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Non-Destructive Testing

THE potential dangers of a mishap to a nuclear installation place the highest premium on the integrity of the plant and the integrity of the components that go to make up this plant. Moreover, personnel safety is not the only consideration; a great deal of capital can be tied up in these installations and once a circuit has been activated the opportunity for maintenance is limited. Even if repair operations are possible, they will be expensive and time-consuming, whilst the down-time alone will be costly. Prior to commissioning, both major and minor plant components are required to pass the most rigorous tests, and the non-destructive testing of fabricated items assumes a significance in nuclear engineering which is probably unequalled in any other engineering field. Although this is now generally recognized, it has still not been fully accepted by all managements and workers.

The requirement for top-quality work extends through from the raw-material manufacturer to the fabrication shop, to the sitework, to the inspectors and, finally, the commissioning engineers. Each of these different groups requires not only to check on its own workmanship, but also to satisfy itself that the previous operator has performed his functions to the highest standard.

Apart from its direct value as a fault-finder, non-destructive testing is a most effective goad, and represents a major psychological weapon in the war on inferior quality. Perhaps the most valuable aspect of non-destructive testing is this effect it has of keeping people up to the mark.

So important a feature is it of nuclear construction that it is in danger of becoming something of a fetish, and an end in itself. By this we mean that there is a tendency, when writing specifications, to call for a multiplicity of non-destructive tests, irrespective of the difficulty and irrespective of the cost. It is always easier on paper to double up the inspection demanded rather than run the risk of a fault developing which has not been foreseen. Nonetheless, inspection of the same joint by X-rays, ultrasonics and magnetic-crack seems an unnecessary extravagance, and such a requirement is not altogether unusual at present in this field.

Postulating virtually impossible faults and introducing testing methods to show them up has two dangers. If none is ever detected there is the temptation to conduct the inspection somewhat carelessly, and although this may not matter, if this is truly an unnecessary operation, such an attitude of mind can spread to other, more vital, testing and lead to the acceptance of sub-standard products. It is too easy to underestimate the psychological importance of this. The other danger is that the manufacturer is led into thinking that the testing will show up any faults that could possibly exist, and relaxes the standard of workmanship, feeling it more economic to execute the job rapidly and in a relatively slipshod manner, accepting the resultant increase in the proportion of rejects.

A most important criterion in the application of non-destructive testing techniques is in appreciating the limitations of such techniques. Although the various systems are improving year by year, non-destructive testing cannot by any means show up all the faults that can exist in a fabricated structure. In the examination of welds, for example, radiography will show the presence of cracks and inclusions (if these are not in a disadvantageous plane), but no information can be adduced as to the crystallographic nature of the weld or the depth of inter-penetration. The basic technology of producing sound welds must have been proved beforehand, by the preparation of samples and the careful inspection by destructive testing techniques. Similarly, non-destructive testing can give no information on such important aspects as the brittle ductile transition temperature, nor can it show changes in this temperature under the action of irradiation. This is regarded in some quarters as probably the most critical aspect of pressure-vessel construction and subsequent operation, yet no non-destructive testing so far devised can help.

Even where non-destructive testing techniques are capable of detecting flaws, the interpretation of the information derived from the test, in terms of the physical fault, and the interpretation of the physical fault into terms of reliability or integrity invariably contain a very large human factor. Standards have been laid down as to the methods in which many of the testing operations should be conducted, and a broad guidance has been given on the acceptance levels, as denoted, for example, by the classes in welded fabrications, but the definition of these classes is by no means precise. Ultimately, the decision for acceptance or rejection will lie either with the insurers or with the owners, or with both in collaboration, and in many instances the specific levels which determine the rejection/acceptance demarcation are arrived at upon the

site. There is much to recommend this approach, when highly qualified people can discuss the problem and arrive at a joint decision, particularly in the absence of more precise data. The problem, however, increases rapidly as the number of interested parties increases and the time and trouble required to define the limits can reach unreasonable proportions. It is to be remembered in this context that on a nuclear-power station site, for example, there are likely to be involved the component supplier, the main contractor, the generating authority, the Atomic Energy Authority, the insurers, and, perhaps, consulting engineers.

Clearly a great deal of research is necessary into the correlation of fault symptoms and the faults themselves, and still further research into the correlation of faults and the consequent threat to the structure. There are many authorities concerned in this, and one suspects that the machinery for collaboration does not work as well as it might. One of the reasons for this is that individual fabricating companies conducting their own research are loath to make the results of their work available to their competitors or the manufacturers of non-destructive testing equipment. Whilst one can appreciate the desirability of being reticent on fabrication techniques, reticence on the technique of examination and the significance of flaws seems unreasonable. We would urge manufacturers to make more freely available the results of their investigations.

An additional reason for the secrecy may be that manufacturers feel that the more polished the techniques of non-destructive testing become, the less dependence there will be upon the skill of the fabricating concern. In reality, the opposite is true; testing can only be an adjunct to good fabrication practice, and can never be a substitution for it. As techniques become more refined, certainly the ability to detect faults and so eliminate them will increase (at a cost), but there will still be those large areas of uncertainty which non-destructive testing cannot probe, and where only experience can give confidence.

Industry as Research Reactor Operators

WITH the opening of MERLIN by H.R.H. the Duke of Edinburgh on Friday, November 6, at their research laboratories at Aldermaston, A.E.I. initiated a new phase in industrial research and development. The reactor is the first to be built and owned by a commercial organization in this country, and it will be available not only for the company's own research activities, but also for the use of the southern Universities. Already the Universities of London, Reading and Southampton have expressed interest, and, indeed, collaboration and joint research has already started.

By this collaboration with the Universities, A.E.I. have established a pattern of operation which could provide the basis for similar projects up and down the country. The Universities and the National Institute are at present discussing their requirements for research reactor facilities, and these would seem to fall into two main categories. The first category covers reactor research as such, which involves the construction of a relatively small private facility (preferably at the University concerned) organized and run by the University. The second category comprises joint facilities for irradiation, in which the reactor is essentially a high-flux source of neutrons only; this is required not so much perhaps by the engineers and physicists, as by the metallurgists, the chemists and the medical faculties.

The location of such a facility is less critical than that of a reactor research assembly, although the examination of isotopes of short half-life will, undoubtedly, figure prominently in research programmes. This work could, however, be conducted in the laboratories attached to the reactor itself, whilst the bulk of the research was conducted in the Universities' own laboratories.

The operation of such a reactor is a completely separate function, and entails a responsibility which many of the Universities do not wish to have and still less do not wish to share. It would seem desirable for a third party to be brought in to undertake this task, and present plans would seem to indicate either the Atomic Energy Authority or the National Institute. The attractions of the Authority as responsible operator lie in its accumulated experience, and also in the possibility of operational costs being partially absorbed into the Authority's own expenses. The Authority is, however, a very large organization, and such an activity could only be a sideline. Furthermore, its responsibility as an advisory body is compromised, and if subsidies are felt desirable, these can appear in the guise of fuel-element loans and the like.

But the National Institute does not seem the proper body either. It is a polyglot organization, and the governing body can only be representative of sections of the Universities, and will inevitably include interested parties. Collaboration between different University bodies is notoriously difficult to organize, and it would seem essential to limit the activities of the Institute to those of an advisory body exercising, where necessary, central administrative control only. Indeed, the terms of reference of the Institute do not seem suitable for the creation of a corps of professional reactor operators.

The alternative would be to employ an industrial organization as the reactor operator, in much the same way that the U.S. AEC employs industry to operate, for example, MTR and ETR. The AEC has found this a highly satisfactory procedure, the independent control leading to a simpler and more certain organization of the reactor's safety and to smoothing the relations between users who may be in competition.

The happy relationship between A.E.I. and the Universities who have already been concerned with MERLIN indicates how successful this mode of operation can be in the U.K. We hope, therefore, due consideration will be given to this precedent that has been established.

DIGEST...

Surveying Significant News

SENN Only Euratom/U.S. Power-station Proposal Confirmed

The address given by M. Hirsch to the American Nuclear Society and Atomic Industrial Forum (page 459) will do little to mitigate the disappointment that U.S. manufacturers feel over the breakdown of the 1,000-MW-by-1963 programme outlined in the U.S./Euratom power-building agreement. Euratom itself is philosophical about its failure to convince the utilities within its domain of the desirability of building now, and does not regard it as any criticism of its own policy or threat to its authority. As we have previously suggested (*Nuclear Engineering*, February, 1959), the R. and D. programme is regarded as being of much greater importance and carrying much greater significance.

British Programme Misquoted by Euratom President

In seeking to justify European reluctance M. Hirsch speaks of his "British friends, with a stockpile of 50 million tons of coal (who) have just decided to postpone for about two years the deadline of their present ambitious programme." Two years ago the programme was extended to cover the period up to 1966 instead of 1965 but no alteration has been made to the 5,000-6,000 MW target nor is any further extension contemplated. M. Hirsch shows a regrettable lack of understanding of British aims and we hope that the misconception is not shared by the bulk of the Commission nor by the directors of European utilities.

U.S. Delays Delivery of Canadian Uranium

Although not unexpected, the U.S. Government's decision not to take up options to buy Canadian uranium after the present contracts expire in 1962-3 means a considerable tightening in the production of the metal in Canada. Commenting on the situation Mr. R. Winters, president of Rio Tinto Mining who control 40% of the Canadian production, has said that he is surprised at the Canadian Government's acceptance of the proposal for stretching out the present contracts. The proposal, by the U.S. and U.K., means that although no more uranium will be bought, it will enable producers to continue for a longer period but with reductions in profit. No doubt the smaller and less efficient producers will rapidly fall by the wayside.

Dresden BWR Core Critical

The first privately financed power reactor in the U.S.A. has gone critical. The dual-cycle BWR built for Commonwealth Edison by the General Electric Co. is fuelled by uranium oxide, enriched to 1.5%, clad in zirconium, the total loading, comprising 488 assemblies, being 58 tons. The reactor diverged with only 28 assemblies in position. Total reactivity required is 11.6%, controlled by 80 control rods. The marked difference between critical and total loading emphasizes the opportunities that exist for spatial instability in large cores.

Concrete Pressure Vessels

Although the first French power stations (EDF 1 and 2) will not follow the G2/G3 pattern (pages 435 to 437) of combining the pressure vessel and biological shield in one reinforced-concrete structure, the possibility of other designers adopting the principle should not be ruled out. The U.K. consortia have also been considering concrete pressure vessels and at least one such design is likely to be included in the Dungeness tenders.

Galbraith Report Still Under Consideration

The findings of the Galbraith Committee have been available to the Government now for nearly four months, but the Election has prevented any action being taken. In the reshuffle, the Ministry of Transport has taken over responsibility for Merchant Marine development, which would indicate a firm division between Merchant and Naval nuclear-propulsion projects. Admiral Wilson stated recently that he expected that Government policy would continue to be based on the thesis that prestige is best served by concentrating on the development of an economic ship, or at least a system which is well on the road to being economic.

Min. of H. and L.G.'s Radioactive Substances Bill Given First Reading

A Bill to extend and unify controls over the discharge of radioactive materials was given its first reading in the Lords on November 12. In its provisions, temporary controls now existing will be made permanent; users will be required to register with the appropriate Minister; authorization for disposal will be required from the Minister; the Minister will have power to set up a national service for handling waste which cannot be dealt with by local authorities.

U.S. AEC Chairman Discusses CTR Collaboration with U.S.S.R.

Speaking at a Press conference in London recently, Mr. John McCone, chairman of the U.S. AEC, expressed his satisfaction with the exchange of information with the U.K. AEA. He also said that he did not think that if an agreement were signed with the Russians, it would be quite as comprehensive. Mr. McCone did not make any positive answers to the possibility of a joint U.S.-U.S.S.R. thermonuclear research programme with the U.K. as a possible participator. He did disclose, however, that the Russian nuclear energy head, Prof. Emelyanov, will be visiting the U.S. this month, for the second time this year, and that he will be joined by Lord Plowden.

AECL Reaffirms Faith in Heavy-water Reactors

The forthright criticism of Canada's power programme by Mr. Winnett Boyd has been countered by an equally spirited reply by the President of Atomic Energy of Canada, Ltd. In his reply to the Ottawa branch of the Engineering Institute of Canada, Mr. Gray reiterates the arguments in favour of heavy-water moderation, and emphasizes the necessity for a relatively small organization such as AECL concentrating all its efforts on one particular technology.

Export/Import Bank Approves Loan for SELNI Project

A credit of $34 million is to be made available by the Export/Import Bank to Societa Elettronucleare Italiana for the Westinghouse 165-MW station. The credit, which is to be guaranteed by the Italian Government, is payable over 15½ years, commencing in 1964. This will cover expenditure in the United States for equipment, materials and services. Total cost of the plant is estimated to be $64 million.

Rôle of U.S. National Laboratories Criticized

The competitive nature of the National laboratories in the United States came in for criticism by Mr. Chauncey Starr in an address before the Atomic Industrial Forum in Washington early in November. An appeal is made that the national laboratories should concentrate on providing the new scientific and engineering information needed to advance the art of nuclear engineering, rather than act as competitors to industry in the awards of development contracts. The AEC has invested in the national laboratories approximately $1,000 million and operating expenses approach $500 million a year. The suggestion is also made that industry should put its house in order and prepare a unified policy which properly recognizes the profit motive.

IAEA Publishes International Directory of Radio Isotopes

The *International Directory of Radio Isotopes* published by the IAEA is an impressive document which lists all the isotopes commonly required by research and industrial organizations, quoting suppliers and, where possible, prices. Fifty-two suppliers in 17 different countries are mentioned, and a useful foreword on handling and irradiation facilities is included. Although prices quoted are reasonably consistent, marked variations do exist, and customers now have a ready reference to hand, which will allow them to buy in the cheapest market.

Estimating Future Demands of Materials and Components

Forecasts of future demands would be of great value to the companies who are regularly supplying equipment to the research and development organizations, but no appropriate channels of inquiry appear to exist. Many items of equipment can now be considered standardized products and many items are also purchased in considerable bulk. If, however, companies are to plan their production and so cut costs, some estimate not only of Authority requirements but of outside requirements would be invaluable.

Reactor Briefs

Commonwealth Edison Dresden's 180 MW boiling water reactor near Chicago achieved criticality on October 15. . . . Two pressurized water reactors of land-based prototype nuclear ship propulsion units went critical on September 15 at Idaho Falls. . . . Duke of Edinburgh opened MERLIN, Britain's first privately owned research reactor, on November 6.

Condensation in a Reactor Containment Vessel

By D. H. JUBB
Rolls-Royce, Ltd.)

Fig. 1.—General view of the test equipment prior to fitting thermocouples.

In an attempt to simulate a serious steam leakage into a reactor containment vessel, and to enable the resultant pressure to be estimated (allowing for heat loss to the vessel) steam was injected into a Lancashire boiler. Two formulæ have been derived, enabling the heat transfer to be estimated.

AN accident to a nuclear power reactor, or to its cooling circuit, might involve the escape of radioactive coolant or fission products into the containment vessel. With steam-cooled, boiling water or pressurized water reactors, the resultant containment pressure would be high, and the vessel must be heavy and expensive. It is, therefore, important when designing such a vessel to allow for the reduction of pressure caused by condensation of the released steam on the vessel walls, and to know the temperature that these walls will attain.

The object of the tests described was to determine whether the loss of heat by a contained mixture of steam and air is sufficient to cause any substantial alleviation of the pressure built up. No relevant information was available on heat loss by condensation of steam in a closed vessel in the presence of air, nor of the effect of a steam jet in promoting mixing and motion of the vessel contents.

The accidental release of steam was simulated by injecting steam at various rates into a Lancashire boiler, and as only one drum of fixed size was available, the initial air pressure was varied. It was felt that the heat transfer must be dependent in some way on steam jet velocity, and probably on a Reynolds number; if the characteristic length term were the hydraulic mean diameter of the drum, variation of this term could be simulated by varying the steam/air density, i.e., by varying the initial air pressure in the drum.

Nine tests were made in all using three orifice plates and three initial air pressures. In two of the tests, the direction of injection into the boiler drum was reversed to determine whether the distance travelled by the jet was a significant factor.

Test Apparatus

The arrangement of the steam receiver and instrumentation is shown in Fig. 2, and a general view of the equipment (before thermocouples were fitted) in Fig. 1.

Steam Supply. Steam was supplied by two Lancashire boilers at approximately 120 p.s.i.g., and was assumed to be about 3% wet. No reliable method of checking this figure was available, but for a true wetness of 0-6%, the steam enthalpy would be within ±2.2% of the assumed value.

Steam Flow Measurement. The steam flow was measured by one of three sharp-edge orifice plates of 1.000 in., 1.375 in. and 1.750 in. diameter, in a 3-in. bore housing with D, D/2 pressure tappings. Several hours after injection, the condensate was released and weighed, to enable indicated steam flows to be corrected to true flows. Allowance was made for uncondensed vapour left in the drum.

Steam Receiver. The steam receiver was a Lancashire boiler, 8 ft 3 in. dia. by 30 ft. 0 in. long, with two 3 ft 0 in. dia. flues blanked off at both ends. The shell was unlagged, and painted externally with red lead, but most of the exterior was partially insulated by the brickwork setting.

The inner surface of the boiler drum was lightly pitted above the water line, and covered with fine rust particles. Below the water line, the inner surface was covered with boiler scale, up to ⅛ in. thick in places. It is assumed that the resistance to heat transfer of the scale and rust is at least equal to

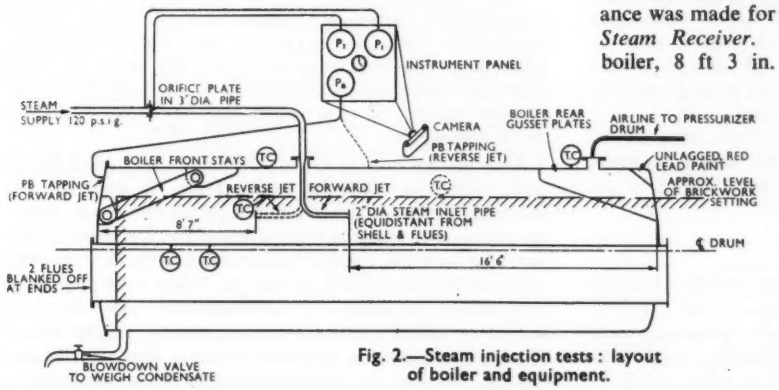

Fig. 2.—Steam injection tests : layout of boiler and equipment.

the resistance of the paint which would be applied to a reactor containment vessel, and of any other insulant, e.g., oil, deposited during service.

The air pressure in the boiler at the start of each test could be varied by admitting air from an oil free reservoir and compressor; initial air pressures of 0, 20 and 40 p.s.i.g. gauge were used.

Instrumentation. Three 8-in. standard test pressure gauges were mounted on the instrument panel; two showed steam pressure upstream and downstream of the orifice plate, and the third showed steam receiver pressure (and hence, by calculation, steam/air temperature). These gauges, and a clock, had black dials and white markings to facilitate photographic reading.

Six thermocouples were welded to the outside of the boiler shell and to the inside of a boiler flue as shown in Fig. 2. They were connected to a Honeywell-Brown indicator and read in turn during and after steam injection. Readings were corrected for instrument error, averaged (in pairs), and weighted for the shell area to which they applied. Thus, an overall average temperature for the outside of the shell was obtained, and the inside temperature was deduced by adding an estimated temperature drop through the shell itself, assumed to be half the drop that would occur if all the heat given to the inside surface were to pass through the shell, i.e., no heat were retained by the shell.

Experimental Procedure

In the pressurized tests, the air was compressed initially to about 2 p.s.i. above the required value, and released via the blowdown valve; this method expelled any further condensate from the previous test. In seven of the tests the steam was directed towards the rear of the boiler, and would travel approximately 16 ft 6 in. along the jet centre line before reaching this face. In the other two tests the steam was directed towards the front of the drum, and would travel about 7 ft before reaching a (sloping) front stay.

The steam was turned on and photographs taken at suitable time intervals of the instrument panel during and after steam admission. At the same time, the thermocouple readings were noted in turn at 10 second intervals, i.e., each thermocouple was read once per minute. Special care was taken to open and close the steam inlet valve as rapidly as possible to minimize the uncertainty of flow during these periods. The standard time of steam injection was 10 minutes; for the next 50 minutes, pressure and temperature readings were taken as the contained steam/air mixture lost further heat under static conditions.

Some hours later, the condensate was released and weighed; the residual steam and air under pressure were then released. The boiler was then left for several hours (usually overnight) with the blowdown valve open to allow any further condensate to run off, and to ensure that the inside surface would be fairly dry and of uniform temperature for the start of the next test.

The test results were analysed in two parts, viz.: forced convection heat transfer, relating to the steam injection period, and free convection heat transfer, relating to the post-injection period.

Forced Convection

Attempts were made to correlate the results obtained on many different bases, including Nusselt and Grashof numbers, on a mass transfer-heat transfer basis and on a jet kinetic energy basis,[1,2] but no useful result was obtained.

Symbols

St	:	Stanton number$=h/C_pG$
Pr	:	Prandtl number$=C_p\mu_i/k$
Re	:	Reynolds number$=pvD_m/\mu$
h	:	Heat transfer coefficient$=H/\Delta T$, B.t.u./ft², sec, °F
H	:	Heat transfer rate per unit area, B.t.u./ft², sec
A	:	Total surface area of boiler shell, ft²
ΔT	:	Temperature difference between steam/air mixture and estimated temperature of inner wall of boiler shell, °F
C_p	:	Specific heat of steam/air mixture, B.t.u./lb, °F
G	:	Mass velocity of steam jet, lb/ft², sec
μ	:	Viscosity of steam/air mixture, lb/sec, ft
k	:	Thermal conductivity of steam/air mixture, B.t.u./ft, sec, °F
ϱ	:	Density of steam/air mixture, lb/ft³
v	:	Velocity of steam jet, ft/sec
D_m	:	Hydraulic mean diameter of boiler shell$=4V/A$, ft
V	:	Volume of steam/air space of boiler shell, ft³
P	:	Absolute pressure of steam/air mixture, atmospheres

The only reasonable basis of correlation was based on Reynolds number, modified by pressure ratio, of the form:

$$St \,.\, Pr^x = K/Re^y\, P^z \qquad .. \quad .. \quad (1)$$

The method of least squares gave the index x a value of approximately 0.5, leading to the formula:

$$St \,.\, Pr^{0.5} = 0.0730/(Re\ P)^{0.263} \qquad .. \quad .. \quad (2)$$

Rounding off the index of (ReP) to 0.25 gave the formula:

$$St \,.\, Pr^{0.5} = 0.0576/(Re\ P)^{0.25} \qquad .. \quad .. \quad (3)$$

and this function is plotted in Fig. 3, together with all the points obtained.

The choice of the same index for Re and P is justified by the fact that the separate indices were found to be in the region 0.25-0.3.

Equation (3) has the advantage of indicating slightly conservative heat transfer coefficients at the low values of $Re\ P$, and it is in this region ($Re\ P$ below about $40\text{-}50\times10^6$) that caution must be used.

The results were obtained over the following ranges of values:—

steam flow	40-160 lb/ft², sec
total pressure	1-8.5 atmospheres
ΔT steam-shell	35-102°F
Re	$13\text{-}68\times10^6$
steam/air ratio	0-3.1

The probable error, calculated from all points, and using equation (3) was $+6.9\%-6.3\%$.

While there is appreciable scatter of points about the recommended curve, the negative probable error of 6.3% means that equation (3) can be used with confidence to assess heat loss by condensation on the walls of a containment vessel; this is particularly so, in view of the heat transfer barrier of rust and boiler scale encountered in the experiments.

Also plotted in Fig. 3 are the results obtained for the tests 1RB and 3RB, in which tests 1B and 3B were repeated, but with the steam jet facing the front face of the boiler, i.e., blowing onto a wall face 8 ft 7 in. distant, instead of one 16 ft 6 in. distant. Moreover, in the reverse jet case, the centre line of the jet meets a sloping boiler stay at approximately 7 ft downstream. The reverse jet results lie quite close to the corresponding results 1B and 3B, and to equation (3), and indicate that the distance travelled by the jet before impinging on a cool surface

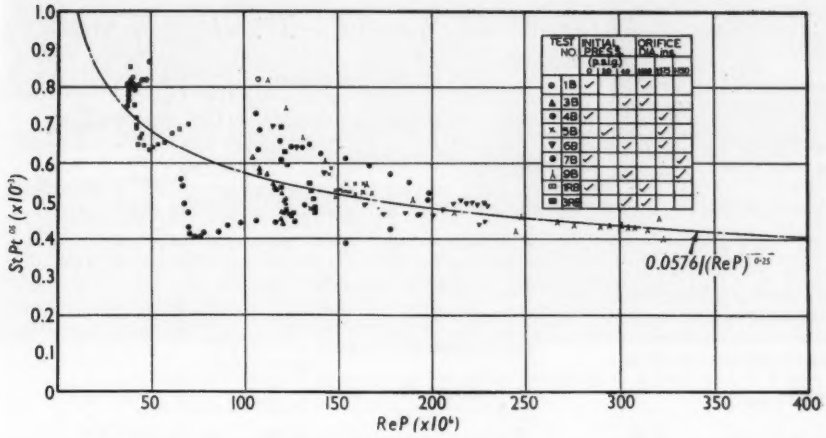

Fig. 3.—Forced convection non-dimensional heat transfer.

does not materially alter the heat transfer. Two reasons are suggested for this result:

(1) The heat transfer, circumferentially and axially, in the boiler shell is sufficiently good to prevent very large differences in surface temperature, and heat given up locally to the shell is quickly dispersed to the surrounding parts, so that further heat can be given to the hot spot.

(2) Given a reasonable distance for the steam jet to mix with the air, a proportion will do so, and give up its heat over a considerable area of the shell.

Free Convection

Fig. 4 shows the heat transfer results for the post-injection period, plotted on the basis of H/ρ versus ΔT.

The widespread scatter of points is caused mainly by the difficulty of measuring the temperature difference between the steam/air mixture and the inside wall of the shell. Both these temperatures are difficult to assess accurately, and the difference between them was rarely above 30°F, and after the first five minutes or so, usually under 10°F. The steam/air temperature is very sensitive to total pressure, which is not easy to determine after 10 minutes of steam injection and anything up to 50 minutes of post-injection cooling, since there is liable to be some condensation in the pressure gauge lines, causing spurious readings to be taken. Also, it is not easy to assess a mean temperature of the inside surface of the boiler shell without a large number of thermocouples; moreover, a temperature variation over the boiler shell of several °F would alter the pattern of heat transfer appreciably, particularly in the later stages of post-injection cooling, when the mean wall temperature is quite near to the steam-air temperature.

Attempts were made to correlate the results on a Grashof number basis, on steam/air ratio basis, on a Nusselt number basis, and on factors involving latent heat, but without success.

The only basis of correlation found was to plot H/ρ against ΔT, as in Fig. 4; the centroid of points indicated the mean curve to be:

$$H/\varrho = 0.0152\ \Delta T^{1.25} \quad .. \quad .. \quad (4)$$

The results gave a widespread scatter of points, but no evidence of any dependence on steam/air ratio or pressure (other than their effect on density). The probable errors calculated were $+23\%-18\%$.

These values, while they are high, do allow containment calculations to be made from the result with confidence, provided reasonable caution is taken in cases where the instantaneous heat loss nears (or exceeds) the rate of heat release (e.g., from shut-down heating in the core) to the contained steam/air mixture.

Conclusions

The experimental results obtained provide a reliable basis for calculating the heat loss to a containment vessel by a steam/air mixture. The effect of containment size has not, however, been thoroughly investigated, and further tests on a larger or smaller vessel would be required to be quite certain at this point.

During the steam injection period the formula:

$$St\ .\ Pr^{0.5} = 0.0576/(Re\ P)^{0.25}$$

will enable the heat loss to shell to be calculated, provided $(Re\ P)$ is not less than $40\text{-}50\times10^6$. Below this level, some caution is advised, and the heat transfer coefficient derived should be compared with a figure derived for the free convection heat transfer coefficient.

After steam injection, the formula:

$$H/\varrho = 0.0152\ \Delta T^{1.25}$$

should be used to calculate the heat losses to the containment vessel.

There was no indication that the distance travelled by the steam jet before striking a cooler surface has any great influence on the heat transfer coefficient, although tests were only made at distances 2.1 and 5.0 shell hydraulic mean diameters (42 and 99 jet diameters). Even so, it is felt that these distances are reasonably representative of the conditions that would apply in the case of a broken steam main in a power reactor containment vessel.

(Worked example, see overleaf.)

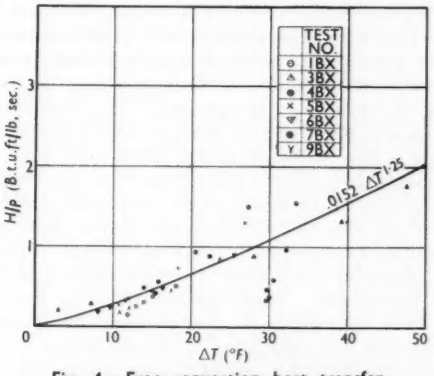

Fig. 4.—Free convection heat transfer versus temperature difference.

ACKNOWLEDGMENTS

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REFERENCES

1. McAdams, W. H. Heat Transmission. McGraw-Hill, London, 1954.
2. Schmidt, E. Thermodynamics. Oxford University Press, 1949.
3. "Steam Cooling." *Nuclear Engineering*, June, 1959, **4**, 39; p. 246.
4. Keenan, J. H., and Keyes, F. G. Thermodynamic Properties of Steam. Wiley and Sons, N.Y., 1956.

Condensation in a Reactor Containment Vessel—*Worked Example*

The containment shell for the Vickers Nuclear Engineering SCHW reactor[4] may be assumed in this example to have the following parameters:

containment volume	$=49{,}870$ ft³
cold surface area	$=11{,}870$ ft²
hydraulic mean diameter	$=16.8$ ft
initial air conditions: pressure	$=14.7$ lb/in.² abs.
temperature	$=135$°F
density	$=0.0667$ lb/ft³
∴ weight of trapped air	$=3{,}326$ lb

Considering conditions in the containment shell approximately three seconds after an accident in which a 16-in. steam main fails completely, and in which the broken ends move apart laterally, allowing steam to escape freely from two 16-in. diameter orifices, assume:

steam flow rate	$=500$ lb/sec
(instantaneous) containment pressure	$=45$ lb/in.² abs.
then:	
steam mass velocity	$=179$ lb/ft², sec
steam/air temperature	$=246$°F
specific volume of steam	$=14.76$ ft³/lb
weight of steam (balance of steam injected has condensed)	$=3{,}379$ lb
steam/air ratio	$=1.016$
C_p for steam/air mixture	$=0.377$ B.t.u./lb,°F
∴ $C_pG=0.377\times179$	$=67.5$ B.t.u./ft², sec, °F
pressure	$=3.06$ atmospheres
density of steam/air mixture	$=0.1345$ lb/ft³
jet steam specific volume at discharge	$=9.401$ ft³/lb

∴ steam jet velocity at discharge $=179\times9.401$
$=1683$ ft/sec

viscosity of steam/air mixture $=12.03\times10^{-6}$ lb/sec, ft

$$\therefore\quad Re=\frac{\varrho v D_m}{\mu}=\frac{0.1345\times1683\times16.8}{12.03\times10^{-6}}$$
$$=316\times10^{6}$$

$$\therefore\quad ReP=316\times10^{6}\times3.06=967\times10^{6}$$

Although this value is well outside the range of test values, the slope of Fig. 3 is very low at high ReP, and the value of $StPr^{0.5}$ may be calculated from equation (3).

i.e. $StPr^{0.5}=0.0576/(ReP)^{0.25}$

i.e. for this example $=0.327\times10^{-3}$

For the steam/air mixture, $Pr=0.918$

$\therefore Pr^{0.5}=0.958$

$$\therefore\quad h=\frac{0.327\times10^{-3}\times67.5}{0.958}=0.0230\text{ B.t.u./ft², sec, °F}$$

∴ heat loss rate $=0.0230\times11{,}870\times(246-135)$
$=30{,}300$ B.t.u./sec

Note:

With the same mixture conditions, but under free convection conditions, i.e. no steam jet to promote heat transfer, from equation (4),

$H=0.0152\times0.1345\times111^{1.25}$
$=0.736$ B.t.u./ft², sec

∴ heat loss rate $=0.736\times11{,}870$
$=8{,}740$ B.t.u./sec

N.B.—The temperature difference assumed here is well beyond the test range, and if it occurred at all in practice under free convection conditions it would only do so momentarily; the example and corollary do show, however, the effect of a steam jet in assisting heat transfer to the containment walls.

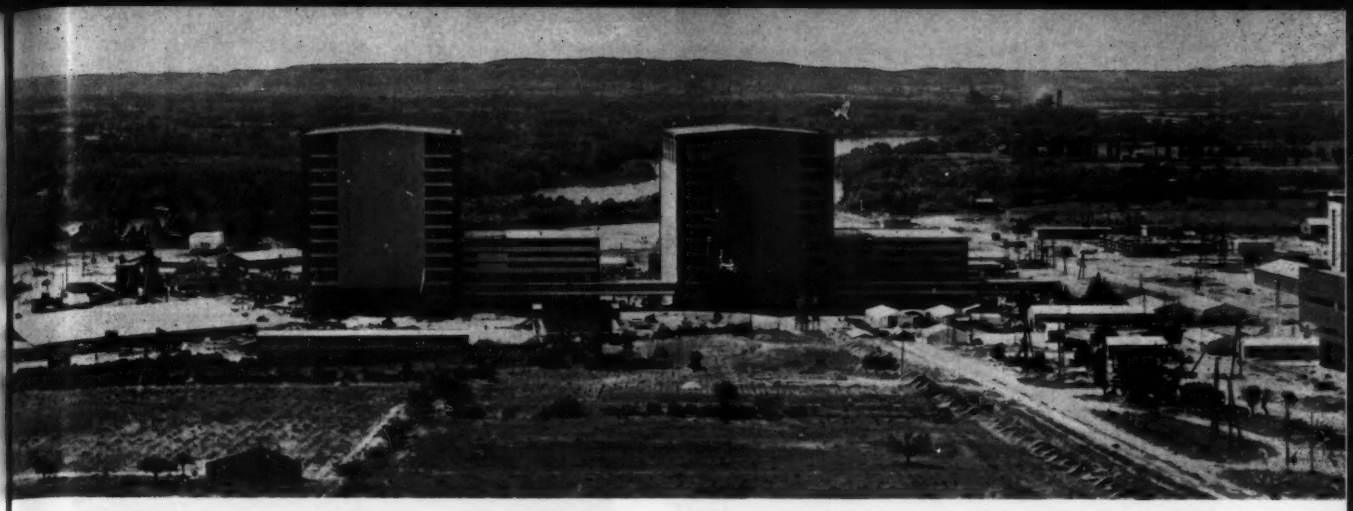
The Functions of Y A R D

Yarrow Admiralty Research Department

THE opportunity was taken before the launch of the anti-submarine frigate "Brighton" for statements to be made of the functions of the Yarrow Admiralty Research Department. This is a unique establishment organized and run by Yarrow and Co., but existing virtually entirely on development contracts from the Admiralty. Since its formation during the war, YARD has built up a reputation for integrity and the ability to think in national terms. As a result, it is in a peculiarly advantageous position to investigate competitive designs and to perform the function of co-ordinating the development of components to be manufactured by competitive companies. In this capacity of an integrating organization, YARD has played a prominent part in assessing the nuclear designs submitted to the Galbraith Committee. These designs (*Nuclear Engineering*, June, 1959) were for a fast fleet-replenishment tanker and the technical sub-committee of the Galbraith Committee extrapolated them to a typical civilian tanker. The conclusions of the Committee have been passed to the Government, who are considering the action to be taken.

With the re-formation of the Government, the responsibilities for a nuclear merchant ship will lie with the Ministry of Transport, but the Galbraith Committee will probably continue to function (although not under Mr. Galbraith, who is now with the Scottish Office), and it will be calling upon YARD for correlative and consultancy services in the near future.

On the Clyde an unusual marine consultancy and research establishment has grown. Its influence in nuclear marine propulsion matters is considerable.



Although designed primarily as plutonium producers G 2 (left) and G 3 each develop 27 MW (E).

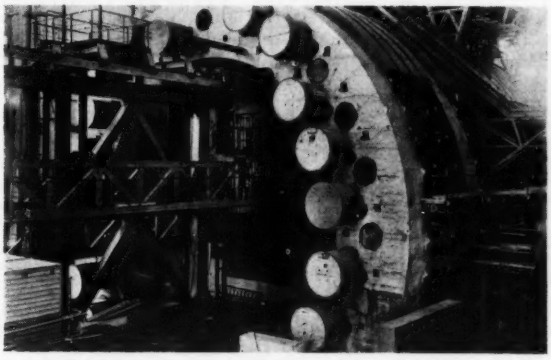
The Marcoule Reactor G 2

G 2 and its almost identical twin G 3 have been built primarily as plutonium producers, but steam is generated in four heat exchangers and each reactor is capable of developing a net electrical output of 27 MW. The *a priori* design consideration of maintaining steam pressures below the reactor coolant pressure (CO_2 at 15 kg/cm^2), to safeguard the reactor in the event of a boiler leak, led to the low thermodynamic efficiencies. The reactor, which is rated at 205 MW (t), first diverged on July 21, 1958, and generated electricity in April of this year.

Construction was made the responsibility of the French consortium France Atome, while the essential reactor design was the work of the CEA and Electricité de France took charge of the generating section. Site work began in September, 1955, but owing to the exceptionally poor weather of that winter, coupled with certain difficulties caused by the absence of complete design data, a full-scale effort was not made until March of the following year. In effect, then, the reactor diverged in a little over 2¼ years from the beginning of the main building.

Outline Design

In sharp contrast with Calder Hall, G 2 comprises a horizontally disposed graphite stack 9m long, enclosed in a prestressed concrete pressure vessel. The core is octagonal in section, mounted on a graphite pedestal which effectively transforms the lower half of the octagon into a half square 9.5 m across. The surrounding vessel is basically cylindrical, with an internal diameter of 14 m, the bottom quadrant being built up into a triangular shape. The vessel rests on a massive concrete base of cellular construction, in which are disposed a number of the ancillary services.



Charge face of the reactor showing charge machine gantry.

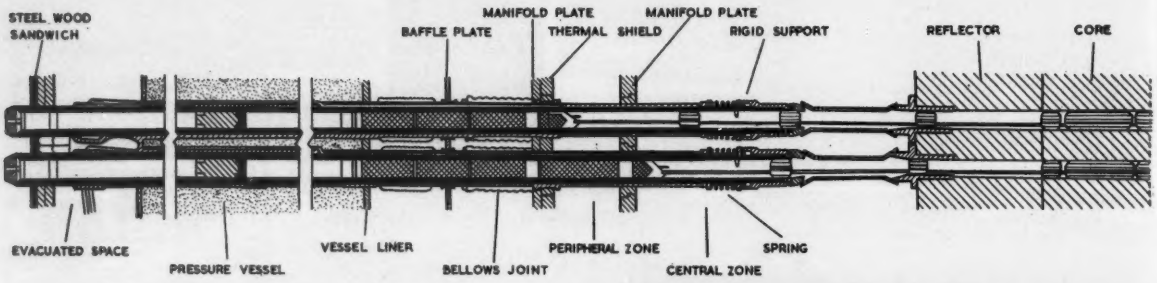
The stack, made from 14,902 blocks, the majority of which are 150 cm by 20 cm by 20 cm, is pierced by 1,200 fuel channels 7 cm in diameter. Semi-circular channels are hollowed out of the long faces of the blocks and the blocks are piled in such a manner that circular channels are formed on a square lattice of 20 cm pitch. Assymetrical positioning of the grooves allows adjacent layers to be placed the opposite way round, so that a staggered build-up of blocks results in the fuel channels being in line.

Complete with its 80 cm of radial reflector and 60-cm reflector on the loading face, the complete stack weighs 1,207 tons. This load is transmitted to the base through rolling supports to a thermal shield of steel carried on 140 screw jacks which, in turn, are supported by five T-section beams bearing on three points across the vessel. The centre of these is a rigid fixture, but rolling supports are provided at the sides to take up expansion. Three further beams carry the 90-cm-thick graphite heat shield behind the discharge chutes, the inlet and outlet manifolds and other constructional features.

Radial Core Restraint

Radial movement of the stack is constrained by 18 straps which surround the reflector and enclose the 12-cm-steel thermal shield plates. This shield is backed by a thermal insulating layer, of crushed aluminium enclosed in steel, and great care is taken in isolating the vessel periphery area from the reactor core. The straps are made up of five beams corresponding to the sides and top of the stack. The two vertical beams are attached at their lower ends through articulated joints to the vessel lining wall; the intermediate linkage between beams which can cater for thermal expansion also translates the thrust to the vessel lining. A positive thrust is exerted on the graphite faces by 972 springs bearing on 270 distribution plates. These springs are required to operate in a CO_2 atmosphere at 200°C, with anticipated excursions during Wigner release of up to 370°C.

Working load for the springs on the vertical faces is 1,880 kg, and an overall movement of 35 mm is specified. The steel chosen for this task is 0.40-0.48% C, 1.0-1.5% Si, 0.4-0.5% Mn, 0.7% Cr, 0.25-0.35% Mo.



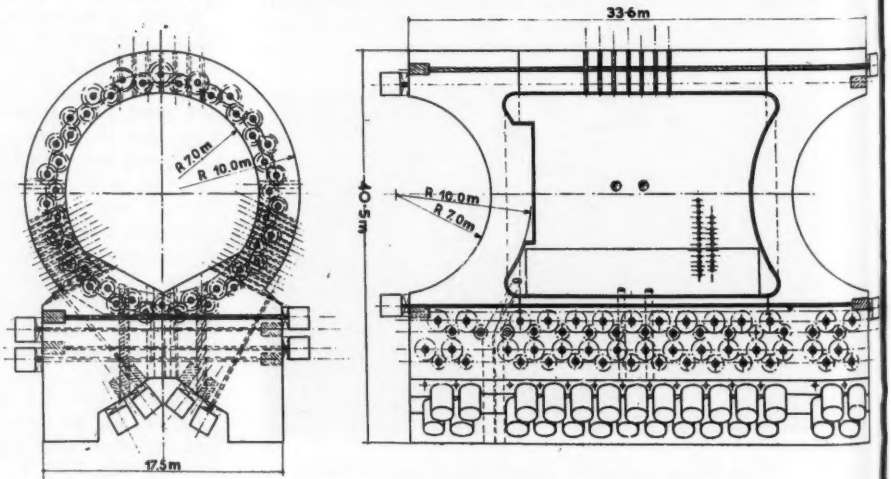
Peripheral and central sprung charge tubes.

The reactor has been designed to charge and discharge under load, the opposite philosophy being adopted in France to that current in the U.K., where plutonium producers have not this facility, but it is incorporated into the generating authorities' power reactors. The horizontal fuel channel arrangement lends itself to a push-through system, new elements being fed in at the gas-outlet end and discharged at the gas-inlet face. The fuel elements are uranium metal rods carried in a magnesium/0.7% zirconium alloy sheath which is longitudinally finned. The cans carry 16 fins, four symmetrically spaced being larger than the others and serving as centralizers in the channel. Overall length is 30 cm, which implies a full channel loading of 28 elements. The core is divided into two zones, the outer zones being able to accommodate rods of larger diameter, viz. 31 mm, as against 28 mm for the central zone.

Two charge machines are mounted on the pressure-vessel face, and these are heavily shielded devices fitted with magazines suitable for loading one complete channel. The irradiated elements are pushed out from the ends of the channel, by the charging action, into inclined, flattened tube guides, one guide serving those channels located on a 45° diagonal; these guides, incidentally, mounted on a steel framework, transmit the locating thrust to the discharge face. Below the last channel the guides transform into a tube, and batteries of these pass through the thermal shields and pressure vessel at an angle of 27° to helical "toboggan runs," where elements attain a standard speed of descent. At the bottom they pass into an automatic conveyor system which cans them in Al before ejecting them to the cooling pond. Some difficulties were met in commissioning the discharge section, due to jamming of elements in the guide-tube transition. Deflector plates were fitted and minor alterations were made to the slopes in the G 3 assembly. The 1,200 channels are served by three systems, one for the central zone and two for the peripheral zone.

The necessity for providing the guide array eliminates the possibility of a reflector on the discharge face. Shielding requirements, however, demand the use of a graphite wall behind the array, to protect the concrete end walls.

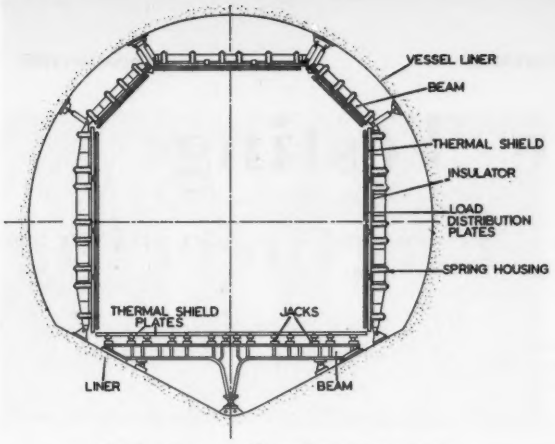
In addition to two-zone loading, two-zone cooling has been adopted, in which CO_2 is fed



Sectional elevations of pre-stressed concrete pressure vessel showing arrangement of pre-stressing cables.

Assembling the hollow rods on the central loading face of the stack. Core and reflector are of Pechiney graphite.

into the peripheral channels at a higher temperature than to the central zone, which has a radius equal to about 0.6 of the core radius. All primary coolant outlet and inlet ducts are brought through the vessel wall at the discharge end, the return circuits being led through the thermal shield, along the reactor inside the pressure vessel, and out of the same wall. The two outlet zones do not correspond to the inlet zones, the central of these having a radius equal to roughly 0.8 of the core radius. Secondary cooling is brought in through ducts in the vessel base and through the wall near the charge end. This secondary gas cools first the charge tubes and charge-wall face, and the bulk is then required to keep the vessel walls cool, emerging through the gap between the 14 ducts and the vessel wall. A bleed is fed inside the thermal shield and round the radial reflector to the peripheral inlet manifolds.



Stack support and lateral restraint system.

where it joins the primary coolant. Traversing the various barriers by these large ducts has presented many problems, particularly in view of the different thermal expansions, and extensive use of bellows has been necessary.

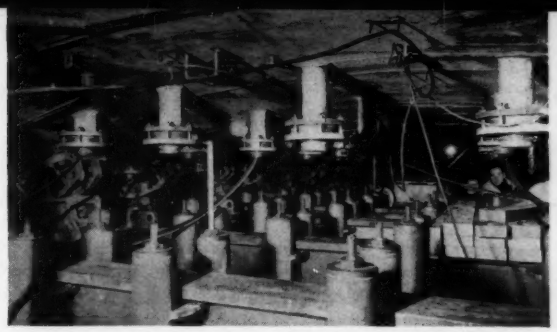
Axial Restraint

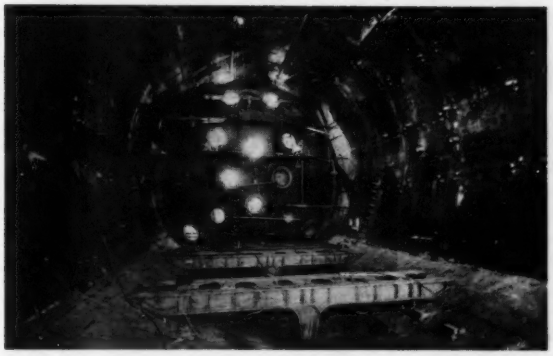
So far no mention has been made of the restraint required to maintain the integrity of the stack longitudinally. Even small pressure differences between inlet and outlet represent a considerable thrust on the end faces of the stack (around 800 tons in practice), and provision must also be made for differential expansions, Wigner growth and contraction without impairing the operation of the charge/discharge gear. Calculations indicate that a rigid restraint on the charge face is not practicable, and some elasticity is necessary, at least over the middle area. The basic thrust is taken by the fuel-channel extension tubes and over roughly half the core area (this area is not symmetrically arranged with regard to the core axis, but has a flattened top) is transmitted through springs rated at 1,440 kg to the vessel wall. Over the rest of the area the thickness represented by the springs is replaced by spacer rings.

Between the charge tube, which carries the sliding tube fitted in such a manner that the movement is limited in both directions to 15 mm, and the fuel-channel bushing, is a hollow rod with flared ends which forms socket joints and so accommodates misalignment. To prevent this rod from disengaging in the event of a large contraction of a localized section of the stack, a second spring of much less power will maintain the slide in contact.

Each charge tube itself is of complex formation and is required to penetrate, in order from the graphite face, the walls of the outlet gas manifolds; the thermal shield; the baffle plate which ensures that the inlet secondary coolant first scours the tube surfaces nearest the vessel wall; the vessel lining; the vessel itself; the additional concrete wall which converts the concave end face into a vertical face; the cover plate and interspace maintained under vacuum; a steel/wood shield—and, finally, the facing plate. Within this tube is an articulated sleeve which can be rotated to adjust the gagging on the channel ports, so controlling the gas flow as well as the shielded plunger, which is withdrawn to recharge with fresh elements. Provision is also made for bringing out thermocouple leads and BSD tubes.

The various sections through which the tube passes all require isolation, and a series of packed glands and bellows units are included. Some problems have been met in obtaining adequate lining up between the entry holes and fuel channels, but these have been overcome largely by increasing the play between sleeve and charge tube.





(Above) Inside the pressure vessel between the liner and the graphite stack. (Below) Entry of main ducts. Thermal expansion is accommodated by SEPI expansion joints.

On the discharge face, thrust must be transmitted to the stack through the discharge guides, the inlet manifold, the graphite wall, the thermal shield and the rear framework. Between the fuel channel and the near face of the inlet manifold (be it central or peripheral) is a sprung sliding tube with spherical ends. The manifold is a rigid structure, side loads being taken by the discharge guides and struts. Between the far face of the manifolds and the framework carrying the graphite wall are rolling joints—and also between the wall (through the thermal shield) and the rear framework. Finally, the load is transmitted to the vessel wall via nine knee-type push rods, one at the centre and eight at the periphery. In this complex system of restraint, the springs required to operate at temperatures of up to 365°C are made of a special steel with $<0.1\%$C, Si and Mn $<1\%$, 50-55% Ni, 15-20% Cr, 15-20% Co, 2-3% Ti and 1-2% Al.

The Pressure Vessel

The pressure vessel itself is an imposing structure. Resting on its massive base, it is 33.6 m long, 40.5 m high and 17.5 m wide overall. The internal diameter is 14 m, and the concave ends have a minor radius of 7 m. The vessel provides the pressure shell and biological shielding, while an inner 3-cm steel lining maintains the leak tightness. It is reinforced by steel cables, and is designed to withstand a pressure of more than twice the working pressure of 15 kg/cm^2. Some 21,000 m^3 of concrete were used in its construction.

The particular design of the lower section of the cylinder permits the banding to encompass 250°, and so avoids cross-over problems. Cable tension is 1,200 tons, applied by three 500-ton oil jacks. The cables were made up on site from over 700 strands of 5-mm steel wire, totalling 5,000 km in length. Great care was required in the preparation of the cable heads, in which the wires are spread and looped over a framework, and also in the application of tension, but little trouble was encountered. It was found advisable to include shoes between the bands and the vessel sides, to reduce the coefficient of friction and spread the load.

Non-Destructive Testing *in Nuclear Engineering*

This article is the first of several in this issue dealing with non-destructive testing and outlines five main systems of interest to the nuclear engineer: capillarity, magnetic particles, radiography by X- and gamma rays, ultrasonics and eddy currents.

By W. E. SCHALL, B.Sc., F.Inst.P.
(*Solus-Schall Ltd.*)

NON-DESTRUCTIVE testing embraces a range of physical phenomena which determine the quality of a material or a manufactured article without altering its chemical or physical structure or properties, or subjecting it to stresses which might shorten its useful life and, indeed, often without even making contact with the specimen under test. To mention these phenomena in the order in which they came into use we have (1) Capillarity in penetrant testing (2) Magnetism in the magnetic particle method (3) Radiography by X-rays and gamma rays (4) Ultrasonic transmission (5) Eddy currents and induced currents. These five headings do not complete the list. There are others which are not yet in general use and, no doubt, still more will appear as time goes on.

Radiography

Taking these five groups in the order of their importance to the nuclear engineer, we begin with radiography by X- and gamma radiation. The choice between these two is a matter of compromise. The thicker the object the higher must be the energizing voltage, but the lower the voltage the greater is the contrast on the film and therefore the smaller are the defects which can be revealed. Then again, the exposure which is necessary increases as voltage decreases. In general one can say that the largest defect sensitivity is achieved with the lowest voltage which still gives adequate penetration and acceptable times of exposure.

The intensity of the radiation from a conventional industrial X-ray tube is far larger than that from the gamma sources which were available until recently.

In addition the focal spot of an X-ray tube is about 3 mm square, but the dimensions of the gamma source have been almost twice as large with the result the geometric unsharpness of the image was much smaller with X-rays than with gamma rays.

At present the most useful and the most exciting application of radiography to testing in nuclear engineering is the examination of welded seams in the construction of the steel shells around reactors. Both X-rays and gamma rays are used at energies from 200 keV to 2MeV—the type being determined by the size, shape and material of the object.

Providing a defect has length, breadth and depth its image will be shown on the film by an area darker than that of the surrounding steel. If the defect is a thin crack it can only be seen if the plane in which it lies and the plane of the rays coincide. If the plane of the crack is orientated at an angle and, more especially, if the crack is very narrow (hair line), it may not be revealed by radiography. Here the ultrasonic beam can act as a pilot: having once established the existence of a defect and its orientation, X- or gamma rays can pin-point the exact shape and size.

X-ray equipment is made for a variety of energies of beam. There are portable units with the X-ray tube and transformer in the same tank, for 200 kV, 260 kV and 300 kV, and there are units for 400 kV movable on lorries with the X-ray tube separate from the transformer but connected by shockproof cables.

Satisfactory work can be produced at 400 kV on 3½ in. of steel but when the thickness exceeds this figure higher energizing voltages become necessary. There are machines which can supply such rays and which depart entirely from the conventional type of high voltage transformer

British Standards and Non-destructive Testing

Non-destructive examination is mentioned in several British Standards. In general these references fall under two headings: (a) specifying tests which form part of a standard: (b) standardizing methods of test so that results are comparable.

Under the first heading, radiographic testing is by X and gamma is mentioned in B.S. 2633, "Metal-arc welding of steel pipelines"; B.S. 1500; "Fusion-welded Pressure Vessels for use in Chemical Industries"; B.S. 1113, "Water Tube Boilers"; and B.S. 487, "Fusion-welded Steel Air Receivers."

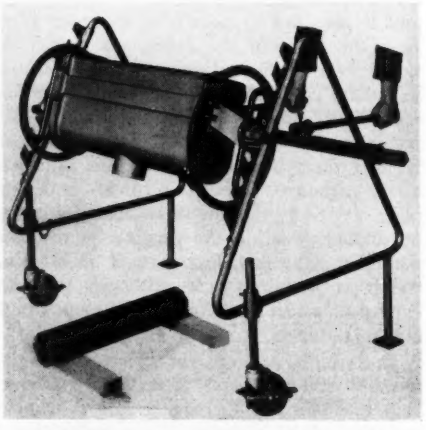
The second heading covers such standards as B.S. 2600, "General Recommendations for the Radiographic Examination of Fusion-welded Joints in Thicknesses of Steel up to 2 in." It should be stressed that this document makes recommendations only —not standards of acceptance. B.S. 2600 is being extended to cover the radiographic examination of fusion-welded circumferential butt joints in pipes with penetrated thicknesses of steel up to 4 in. using the single-wall technique and 2-in. using the double-wall technique.

B.S. 2704 describes standard reference blocks for the routine checking of ultrasonic equipment. Other standards are being prepared on radiology, cable termination for X-ray equipment, dimensions of radiograph capsules and industrial X-ray equipment.

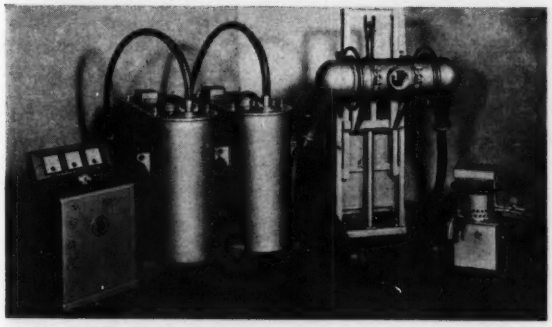
So far as terminology is concerned, Section 6 of B.S. 499 dealing with radiographic terms for welding, is being revised. British Standards also publish glossaries such as "Glossary of Terms used in Radiology" and "Terminology of Internal Defects in Castings."

Other B.S.I. committees are currently studying methods of protecting workers from radiation and the whole subject of crack detection.

British Standards Institution, 2 Park Street, London, W.1.



Portable X-ray unit for site radiography at 200, 260 or 300 kV (Solus-Schall).



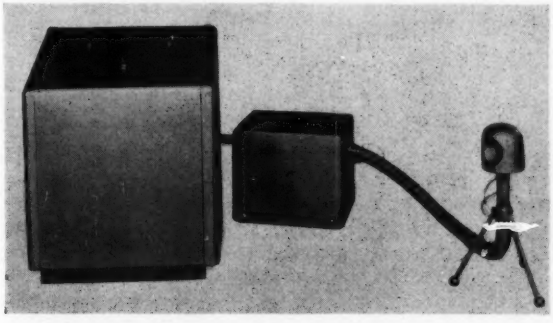
Solus-Schall 400 kV X-ray unit for site radiography with generator transportable on lorry and X-ray tube connected by shockproof cable.

and X-ray tube. There are for instance the Van de Graaf, the Betatron, the linear accelerator and others.

The radioisotope is a convenient alternative—providing, as it does, rays with voltage equivalents of 1.2 MV (cobalt-60), 660 kV (caesium-137) and 450 kV (iridium-192). The containers which have been used until recently could with safety be charged with 5c of iridium or 2.5c of caesium. The fact that gamma rays require longer exposures than X-rays and that the contrast on the resulting radiograph is much less is accepted as inevitable because manœuvrable X-ray apparatus for more than 400 kV is not generally available. And for 3½ in. or less the considerably higher cost of the X-ray unit, coupled with the need for frequent service, is accepted because the sharper definition on the radiograph conforms more closely to the acceptance standards and because the times of exposure are much less.

Within the past year or two, however, matters have changed, partly because standards of work have been altered, partly because gamma sources of much larger energy are now available. A pneumatic container also has been produced consisting of a lead safe housing the source which is propelled by air to the exposure head when the radiograph is to be made and withdrawn again by air in the opposite direction after the exposure is finished. The basic cube of lead will house 10 curies of Co^{60} with complete radiation safety on the surface. Thereafter the safe can be built up by the addition of lead bricks all round till it can house 3,000 curies.

Before this the practice was to radiograph the complete thickness of weld up to 3½ in. with 400 kV X-rays and beyond this with whatever gamma source was available. With the larger sources, however, the tendency today is to radiograph the first few runs of weld with a portable unit



Pneumatically operated source container for 10 curies Co^{60}.

of comparatively low power—say 260 kV at thicknesses of 1 in., 1½ in. and 2 in. and thereafter the total thickness with a pneumatically propelled 1,500 curie unit.

The weight, cost and need for service of an X-ray unit increase rapidly with rise in energizing voltage and therefore the use of lower voltage X-ray units and gamma sources of much greater energy make for cheaper and incidentally, easier working.

Before leaving the subject of radiography a word is necessary on protection. Recommendations for the safety of those who may be exposed to the rays are in draft for incorporation in the Factory Act. After these have been approved by Parliament they will have the force of law. Till then all those whose work or responsibilities are in connection with X- and gamma rays will do well, when in doubt, to consult the draft (H.M. Stationery Office, Kingsway, London, W.C.2), or the Radiological Protection Service, Clifton Avenue, Belmont, Sutton, Surrey.

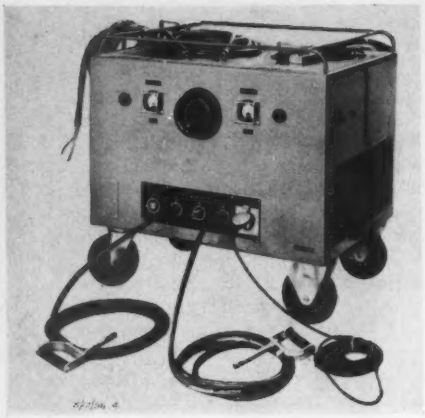
Ultrasonic flaw detector (Solus-Schall).

Ultrasonic Inspection

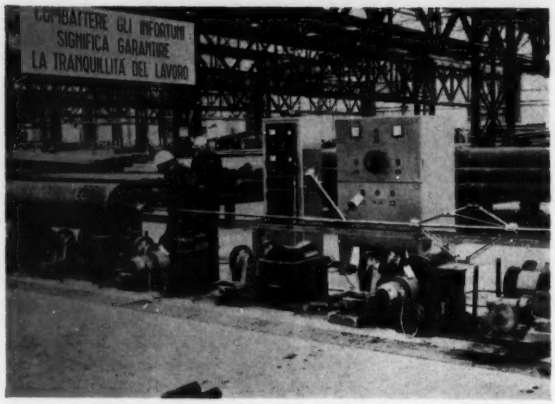
Ultrasonic flaw detection makes use of mechanical vibrations, having a frequency greater than that of audible sound, and capable of being produced in piezo-electric crystals. When an alternating voltage is applied to one axis of such crystals (quartz, barium titanate, lithium sulphate), contraction and expansion occurs along an axis at right angles. The converse is also true, namely that a mechanical vibration applied to the one axis sets up an electrical voltage in the other axis.

The method of test is to transmit the electrically produced mechanical pulses from the crystal to the specimen in which they then travel forward till they reach a boundary. Here they will either be received by a second crystal or be reflected back to the original transmitter. In either case they are reconverted to an alternating voltage which can be displayed on a cathode ray tube.

The important point about the transmission of sound in steel—or other media when homogeneous—is that the pulse travels for very considerable distances with only trifling attenuation. But when it reaches a boundary—or interface between materials—and especially when there is gas on the other side, the pulse is almost completely stopped and reflected—even if the boundary is only a minute crack. Thus there is a fundamental difference between X/gamma rays and the ultrasonic beam because the former is heavily



(Left) Mobile magnetic crack detection unit.



(Right) Magnetic test of rolled or drawn tube. The water-cooled current carrier being inserted. (The photograph and details below are by permission of Dalmini, Bergamo, Italy.)

absorbed by a few inches of steel but will traverse an air gap and continue on the other side as if nothing were in the way. The latter on the other hand will travel in steel for yards without absorption but will be stopped by a hair-line crack.

In the apparatus which produces and records the pulses, two plates of the cathode ray tube control the pulse intensity whilst the other two provide a time base. It thus becomes possible to separate the transmitted pulse from the received pulse in the matter of intensity and time.

When two crystals are used and the transmitted but unreflected pulse is observed, a reduction of intensity at the receiving end as compared with the transmitted pulse indicates the presence of a flaw—but it gives very little information about location, size or shape. On the other hand a single transceiver crystal will display the transmitted pulse, the back wall echo pulse and any intermediate flaw echo pulse. Moreover the time base permits an accurate estimate to be made of the distance of the flaw from the transmitter and, to some small extent, also the shape and size of the flaw. Hence it becomes possible in some cases to scan a welded seam ultrasonically and to reserve radiography for those parts where there is ultrasonic evidence of a flaw, its location having been determined and its size and shape being left to radiographic examination.

Magnetic Crack

Thus far we have dealt with defects which might occur anywhere within the specimen. The crack which is open to the surface or situated close below the surface is susceptible of another form of testing. This is known as the magnetic particle test and is based on the magnetization of the specimen. If there are no defects the magnetic field does not stray but if there is a crack—even an invisible one—which is open to the surface or in a plane at right angles to the field just below the surface it will give rise to a stray magnetic field in the space above. If then finely divided ferromagnetic particles like iron oxide are applied to the surface they will collect in the stray field and show up the crack. A sub-surface crack whose plane coincides with the field will not cause straying and cannot be detected. Magnetization should therefore be first in one direction and then in a second one at right angles to make sure that no crack is missed.

Magnetization can be set up by passing a low voltage heavy amperage current through the specimen between electrodes. The field then surrounds the current cylindrically. Alternatively a current-carrying coil of wire from a mobile unit may wholly surround the specimen and set up longitudinal magnetization. The former is the more usual procedure in the case of welded seams.

Magnetic ink consists of a fine suspension of ferromagnetic particles in a volatile liquid. The latter evaporates leaving the particles in position to reveal the crack. The inks in volatile liquid have proved unsuitable for nuclear engineering because the liquid (paraffin or alcohol) is too inflammable. A new ink—with fluorescent particles which show up under ultra-violet light and which is water based —has provided an answer to the problem.

Another example of induced magnetic field testing which has direct bearing on nuclear engineering is the examination of drawn or rolled steel tubes for cracks, inclusions or laminations. Welded tubes are not suitable for this form of test. An accompanying illustration shows a copper pipe, through which cooling water passes, located along the axis of the tube under test. A direct current of several thousand amperes flows in the copper pipe and sets up a circular magnetic field in the steel tube. Provided that the magnetization is near saturation a longitudinal crack will cause a stray field to emerge. Defects in rolled or drawn tubes always have longitudinal orientation and therefore spiral scanning of the tube when magnetized will reveal them.

The scanning is effected by rotating the tube about its axis by means of rollers whilst a suitable probe is moved longitudinally along the tube from one end to the other. The probe is connected to a Foerster Oestedmeter which gives visual or audible indication when a crack or other defect is encountered and which can be arranged automatically to stop all movement and mark the tube where the defect has appeared. With a magnetization of the tube up to 20,000 gauss a leakage flux of 5-20 Oersted is associated with a defect of approximately 0.02 in. depth. Without going into detail one can say that in the case of 8 in. diameter tubes efficient testing can be carried out at a longitudinal rate of 6½ feet per minute. Moreover pipes with internal diameters from 6 in. to 3 ft can be tested in this way.

Eddy and Induced Currents

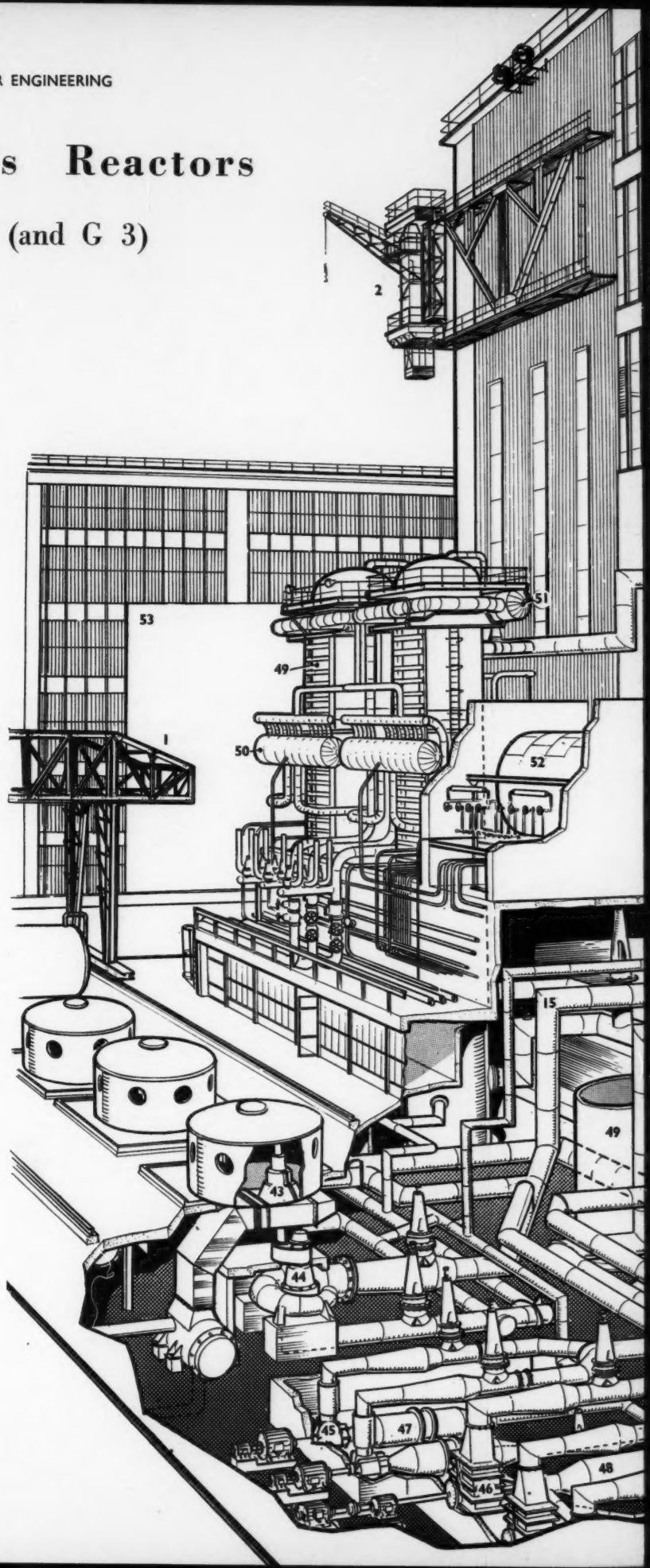
Eddy currents and induced currents which form the fifth group of non-destructive methods mentioned at the start, in general are not used for direct testing of welds. They are, however, of great value in making 100% automatic or semi-automatic tests on large or small component parts in the course of manufacture or in establishing the quality of the material, or in sorting stocks where the possibility of a mix-up exists. Space forbids any lengthy discussion of such methods which make use of variations of conductivity, coercivity and eddy current characteristics of specimens.

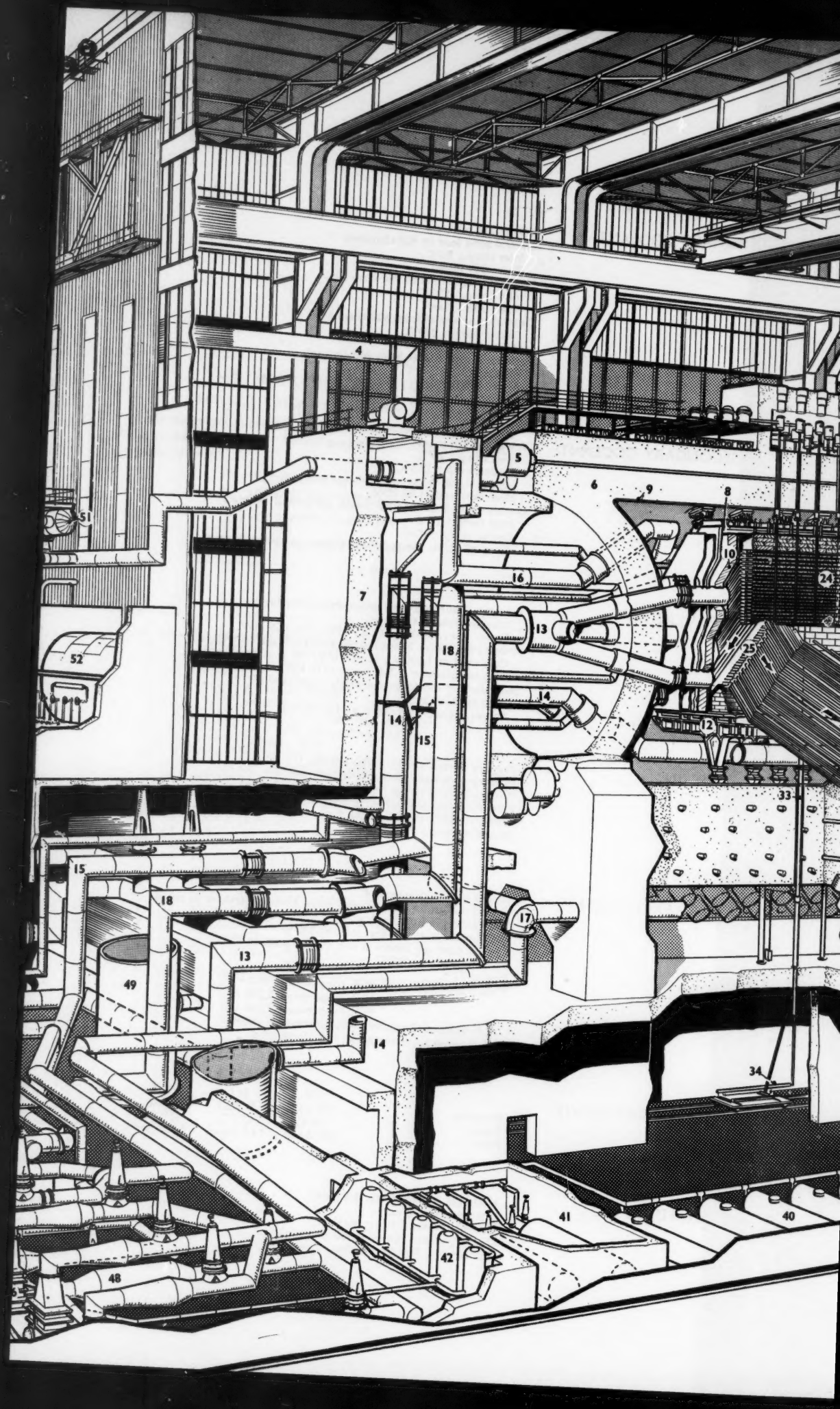
The World's Reactors

No. 24 G 2 (and G 3)

KEY

1. Service crane
2. Heat exchanger service crane
3. Reactor cranes
4. Ventilation duct
5. Concrete pre-stress cables
6. Vessel and biological shield
7. Secondary shield
8. Thermal shield
9. Vessel liner
10. Graphite wall
11. Charging face
12. Core supports
13. Primary central inlet
14. Primary central outlet
15. Primary peripheral inlet
16. Primary peripheral outlet
17. Secondary inlet
18. Secondary outlet
19. Steel sub-shield
20. Removable plugs
21. Control rods
22. Control rod mechanism
23. Graphite core and reflector
24. Fuel elements
25. Fuel element discharge guides
26. Toboggan run
27. Vibro transporter
28. Fuel element feed
29. Fuel element cooler
30. Can storage
31. Fuel element canning machine
32. Hydraulic conveyor to storage pool
33. Ion chamber
34. Ion chamber tube carriers
35. Burst element detection room
36. Compressor room
37. Charge lifts
38. Charging platforms
39. Charge machine
40. CO_2 storage cylinders
41. Refrigeration plant
42. Filter room
43. Blower turbines
44. Primary blowers
45. Primary auxiliary blowers
46. Secondary blowers
47. Primary start-up heaters
48. Secondary start-up heaters
49. Heat exchangers
50. High pressure steam drum
51. Medium pressure steam drum
52. Water feed reservoir
53. G 3 reactor

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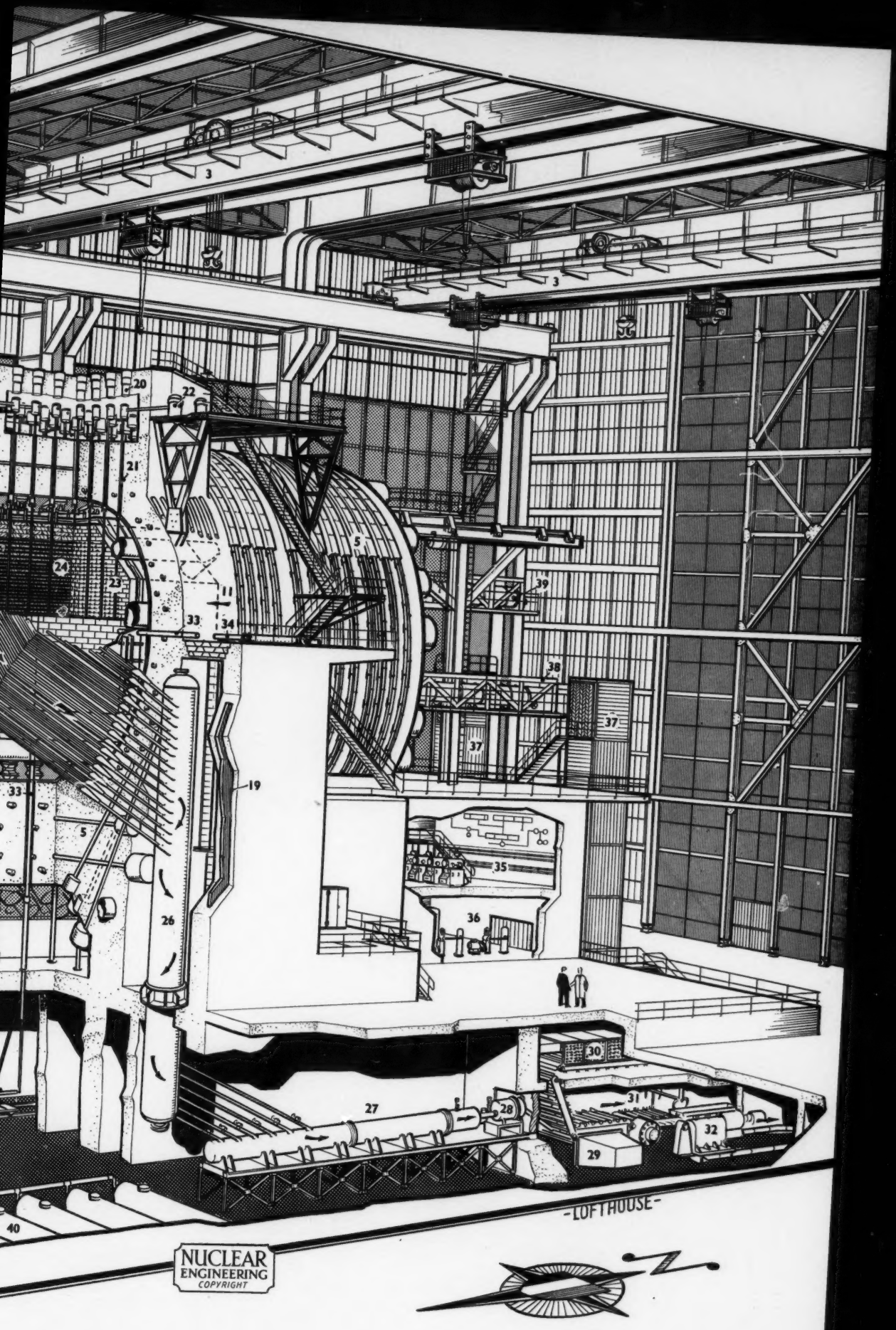
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The World's Reactors

No. 24 G 2 (and G 3)

OWNER: Commissariat à l'Energie Atomique.

LOCATION: Marcoule, France.

TYPE: Thermal heterogeneous.

PURPOSE: Plutonium production; power production.

RATING:
205 MW (t); 27 MW (E).
Installed capacity: 45 MW.

OPERATION:
G2 diverged: July 21, 1958.
Electricity generated: April 22, 1959.

FUEL:
Natural uranium metal rods.
Some central rods, U/0.4% Al alloy.
15–20 channels loaded with Th.
Uranium density: 18.9 g/cm³.
Maximum temp.: 550°C.
Loading: 110 tons.

FUEL ELEMENTS:
Canning material: Mg/0.7% Zr alloy.
Max. temp: 400°C.
Wall thickness: 1.5 mm.
Overall length: 30 cm.
Extended surface: 16 fins, 4 high, 12 low.
U rod dimensions: 28.2 cm long, 2.8 or 3.1 cm dia.
Thickness of end caps: 0.9 cm.
Dia. across high fins: 6.63 cm.
Dia. across low fins: 5.13 cm (2.8 cm rod),
5.43 cm (3.1 cm rod).

MODERATOR:
Graphite.
Density: 1.7 g/cm³ (core),
1.67 g/cm³ (reflector).
Total number of blocks: 14,902.
Standard block size: 150×20×20 cm.
Total weight: 1,207 tons.

CORE:
Horizontal octagonal cylinder, surrounded by reflector, base extended to be parallel with sides.
Length: 8.4 m.
Distance across octagon flats: 8.0 m.
No. of fuel channels: 1,200.
Channel dia.: 7 cm.
No. of elements/channel: 28.
Mean channel rating: 1.82 MW/t U.
Max. channel rating 3.3 MW/t U.
Lattice: regular square, 20 cm pitch.

REFLECTOR:
Lower-grade graphite.
Radial: 40 cm grade 2+40 cm grade 3.
Longitudinal: 60 cm, charge face only.
Maximum stack dimensions: 9.4 m high, 9.53 m across, 9.05 m long.

CONTROL:
Boron carbide rods canned in steel.
No. of rods: 46.
Dimensions: 500 cm×4.0 cm o.d.
Channel section: 12 cm×7.2 cm.
Reactivity controlled: 5.5%.

FLUX:
Maximum thermal: 2.8×10^{13} n/cm², sec.

PRESSURE VESSEL:
Prestressed concrete; horizontal cylinder with concave ends, on massive base.
Internal diameter: 14 m.
Minimum internal length: 15.65 m.
Radial thickness: 3 m.
Minor radius of concave ends: 7 m.
Maximum dimensions: 27.5 m high, 17.5 m across, 33.7 m long.
Total assembled weight: 75,000 tons.
Reinforcing: 46 cables longitudinally,
58 cables tranverse,
56 cables banding, over 250°.
Cable tension: 1,200 tons.
Internal cladding of vessel: 3 cm steel.

PRIMARY COOLANT:

CO_2 at 214 p.s.i.
Central zone feed to 420 channels.
Inlet temp.: 80°C.
Flow: 854 lb/sec.
Peripheral zone feed to 780 channels.
Inlet temp.: 150°C.
Flow: 796 lb/sec.
Central zone outlet from 820 channels.
Outlet temp.: 309°C.
Flow: 1,420 lb/sec.
Peripheral zone outlet from 380 channels.
Outlet temp.: 348°C.
Flow: 230 lb/sec.

SECONDARY COOLANT:

Vessel and structural cooling:
Inlet temp.: 25°C.
Outlet temp.: 29.5°C.
Inflow: 1,100 lb/sec.
Heat removed: 1.85 MW.
Fraction bled into thermal shield, peripheral reflector:
Inlet temp.: 27°C.
Outlet temp.: 90°C.
Flow: 88 lb/sec ejected into primary peripheral stream.

CIRCULATORS:

Primary: 3 turbo-driven single-stage centrifugal.
One retained as stand-by.
Power consumption: 2×3.7 MW+1×2.25 MW.
Primary auxiliary: 2 motor-driven single-stage centrifugal.
One used at 1,000 r.p.m. (60 kW) for shut-down cooling.
Two in parallel at 1,500 r.p.m. (170 kW) for start-up.
Secondary: 3 motor-driven single-stage axial.
Two as stand-by.
Power rating: 2×1,000 h.p., 1×140 h.p.

DUCTING:

Primary central entry: 4×80 cm dia.
Primary peripheral entry: 4×80 cm dia.
Primary central outlet: 4×100 cm dia.
Primary peripheral outlet: 2×80 cm dia.
Primary manifolds: 1.6 m dia. max.
Secondary inlet: 2×1.2 m.

HEAT EXCHANGERS:

No. of heat exchangers: 4.
Type: shell/tube divided into three vertical sections in series.
Shell dimensions: 32 m high×3.5 m dia., 3.1 cm wall.
Peripheral gas enters first inlet at 348°C.
Central zone gas enters at end of first stage at 309°C.
Part extracted at 140°C.
Part at 71°C.
Heat transfer surfaces: H.P. superheater: 450m².
H.P. evaporator: 2,540 m².
M.P. evaporator: 1,360 m².
L.P. boiler and common economizers: 1,760 m².
M.P. fraction superheated by H.P. drum loop.

STEAM CONDITIONS:

	H.P.	M.P.	L.P.
Pressure	153 p.s.i.	31 p.s.i.	7 p.s.i.
Temp.	334°C.	171°C.	81°C.
Flow	105 lb/sec	14.5 lb/sec	7.1 lb/sec

SHIELDING

Minimum 3 m concrete, 2.4 g/cm³.
Charge face: 4.8 m.
Thermal barrier: 15 cm steel.
Discharge face: additional 80 cm graphite.
Max thermal flux to concrete: 7 mW/cm².

THE WORLD'S REACTORS

No. 22 Latina (October, 1959)

We regret that in printing, the figure **5** *indicating the core support diagrid became displaced. Revised annotations have also been received for the following:*

15. High-pressure steam drum
16. Low-pressure steam drum
17. } Low-pressure evaporators
18. }
19. Low-temperature economizer

Pull-outs already published in this series in "Nuclear Engineering" are:

No. 1. BEPO (April, 1956)
No. 2. CP5 (May, 1956)
No. 3. NRX (June, 1956)
No. 4. DIMPLE (August, 1956)
No. 5. ZEUS (September, 1956)
No. 6. CALDER HALL (October and December, 1956)
No. 7. RUSSIAN 5 MW (November, 1956)
No. 8. DIDO (January, 1957)
No. 9. THE SOUTH OF SCOTLAND ELECTRICITY BOARD STATION (February, 1957)
No. 10. BERKELEY POWER STATION (March, 1957)
No. 11. BRADWELL POWER STATION (April, 1957)
No. 12. DOUNREAY FAST REACTOR (June, 1957)
No. 13. EBWR (July, 1957)
No. 14. RWE 1 (September, 1957)
No. 15. LIDO (November, 1957)
No. 16. PLUTO (April, 1958)
No. 17. MERLIN (May, 1958)
No. 18. GI (June, 1958)
No. 19. HINKLEY POINT POWER STATION (July, 1958)
No. 20. NRU (February, 1959)
No. 21. HALDEN (March, 1959)
No. 22. LATINA (October, 1959)
No. 23. ZENITH (November, 1959)

Research at Culcheth

IN order to fulfil its rôle as consultant in the construction of the civil nuclear-power stations, the Atomic Energy Authority undertakes research into non-destructive testing techniques. For its own installations, such as prototype reactors, the Authority establishes standards and acceptance levels in collaboration with the contractor.

Two aspects of reactor construction have been given particular attention. These concern the examination of plate over 3 in. in thickness and the integrity of nozzle welds in thick-plate vessels. It is generally agreed that the limitation of conventional radiographic techniques on site is approximately 3-3½ in. of steel, but as operational pressures rise, so plate thicknesses will increase, and as a check on constructional procedures, some other form of on-site testing is required.

Three general approaches can be made to the testing of very thick plate: X-ray examination using a high-energy X-ray machine such as the linear accelerator; gamma-ray testing with a radioisotope source and, finally, ultrasonic testing.

In collaboration with A.R.D.E., Mullard and Metropolitan Vickers Electrical Co., Ltd., the potential suitability of linear accelerators for radiography of welds in thick plate has been assessed. The equivalent output from such machines is approximately 600 r/min at 1 m, corresponding approximately to a cobalt radiographic source of 25,000 curies. With the tungsten transmission target that is used, a source diameter of around 2 mm is achieved, and the resulting X-ray photographs give a sensitivity that is on a par with present Class I standards—that is, penetrameter tests show a sensitivity of better than 2%.

With the increasing availability of high-strength cobalt sources, the use of gamma radiography is also a practical proposition, and a similar sensitivity can be achieved. One of the major problems is concerned with the physical size of the cobalt source, which effectively limits the source-strength that can be concentrated into an acceptable volume, and therefore imposes a relatively long exposure time.

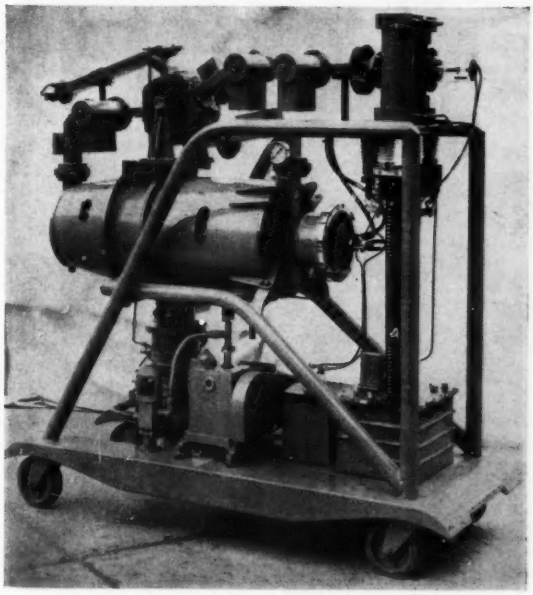
The major difficulty, however, with both these techniques concerns the site organization necessary to ensure no radiation hazards to the site operatives. The radiation doses in the beam are very considerable, and the only possible procedure is for the assembly area to be evacuated during the radiographic inspection. Should the constructional programme require the bulk of the welding operations to be conducted within the biological shield, then the site problem is eased, and it should be possible to carry out radiography without providing substantial additional shielding. Even so, the biological shield would have to be evacuated. Special mounting gear will have to be constructed, of course, but this should not present any great engineering difficulty.

As an alternative to radiography, ultrasonic methods of inspection are also being studied at Culcheth. The first approach has been to attempt a correlation of ultrasonic responses with faults subsequently revealed by sectioning. The ultrasonic system allows detection of any orientation, provided that a comprehensive scanning technique can be used. The basic principles of inspection have been established by manual operation of test probes, but this method of examination is impracticable on the very considerable lengths of weld on a reactor pressure vessel and development is in hand to automate the process. A linear scanning speed of around 5 ft/min appears to be possible, but several scans are necessary to inspect a weld completely. It is hoped to produce an operating machine for laboratory trials in mid-1960, with the object of proving a technique which should be more comprehensive than X- or gamma-radiography, perhaps somewhat faster and not requiring the generation of dangerous radiation.

As with all ultrasonic testing, the difficulty is to establish the sensitivity of the machine so that it will reliably indicate serious faults and yet, at the same time, not respond to trivial imperfections of no practical consequence. An element of judgment is inevitably present, and experimental work to establish the responses to types of defects is necessary before a new method of examination can be considered reliable.

The nozzle entry is a good example of particular welds which are not amenable to non-destructive testing by X- or gamma-ray, but which may be inspected by an ultrasonic method. In a proposed test for nozzle welds, the ultrasonic transmitter and receiver is assembled within the nozzle, the inside wall of which is scanned at various levels. A vertical movement is introduced to follow the weld profile for nozzles which enter at an acute angle.

The efficiency of various magnetic crack-detection techniques for detecting the presence of laminations at plate edges have also been assessed. Whilst ultrasonics are generally used for checking the main area of the plate, an additional check may be required to ensure that any lamination does not come within, say, ¼ in. of an edge which is to be welded. Experiments have shown that a half-wave rectified source of magnetizing current has advantages over pure AC current in revealing sub-surface defects.



Mullard 4 MeV linear accelerator, trolley mounted for industrial or laboratory use.

Radiographic Inspection

By R. S. FORBES
(*Newton Victor Ltd.*)

Use of X-radiographic techniques for examining fuel elements, graphite support struts and welded joints in heavy plate. Possible applications for the linear accelerator and the multi-curie source in the future.

AS reliability is the absolute key-note in nuclear engineering, a large number of parts and components are radiographically inspected simply as a final check on the accuracy of the assembly. Many manufacturers employ this method—especially where the part or component when installed will be inaccessible for service or maintenance. Normal industrial radiographic procedures are used and no special problems are involved in this type of work. It is therefore proposed to describe here the more specialized applications of X-ray inspection in nuclear engineering where the methods differ from those usually employed.

There are three outstanding examples, namely: the examination of fuel elements, graphite supporting struts and the welded joints in reactor shells and heat exchangers. The first two examples are interesting because of the large number of components involved. About one million fuel elements have already been made. Because of the stringent requirement that each casing must be gas-tight throughout its life in the reactor, every possible test and precaution has been adopted to check these assemblies both during and after manufacture. As is well known, the fuel is contained in a tubular finned light-alloy shell with a circular welded joint at each end; the can must be in contact with the fuel to ensure the uniform transfer of heat. Each element end section is radiographed, but it was not thought essential to include the centre section as the method of manufacture ensured that the contact between the fuel and the casing would be better at the centre than at the ends. As the fuel element is essentially circular in cross-section, three radiographs at an angle of 120° at each end are necessary and this meant the rotation of each fuel element between radiographs through this angle. The end cap is welded to the tubular section and here again three views are necessary. In view of the large numbers involved, it was decided to build automatic plant to move and position the fuel elements and to use strip film to record the results. The machine is basically a special conveyor moving the fuel elements into position in a lead-protected cabinet under twin X-ray tubes. The conveyor then stops and both X-ray tubes are automatically energized for a pre-set time. The fuel elements are then rotated, the films moved and the identification number changed, followed by the second exposure. The process is then repeated a third time. The conveyor then moves the fuel elements one stage farther, and a similar procedure is followed for the examination of the welded joints at each end, all movements and exposures being automatically timed and interlocked with the film movements. Several machines of this type are now in use examining fuel elements at the rate of one per minute.

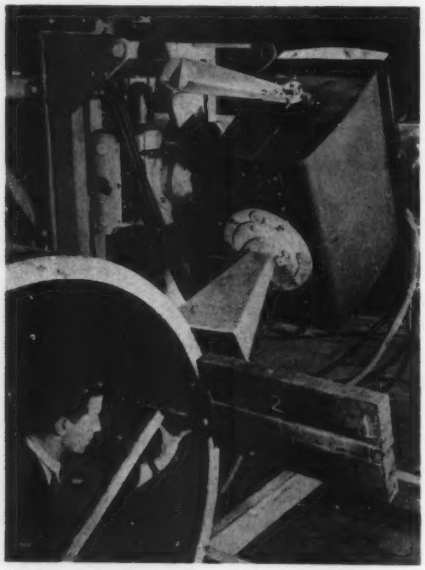


Fig. 1.—Raymax 250 tube head in position for a radiograph of a boiler drum.

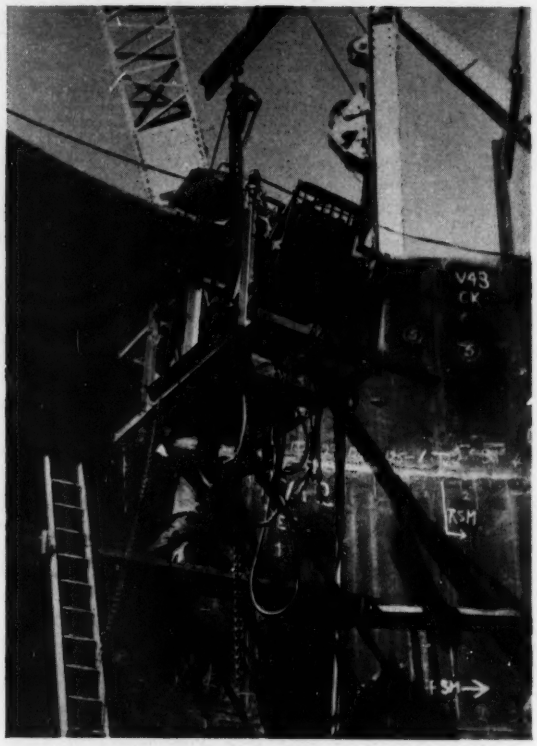


Fig. 2.—Raymax 250 in supporting jig in Calder Hall reactor vessel.

Graphite support struts are intricately shaped and as they are load bearing, cracks cannot be tolerated. Fluoroscopic methods of inspection were tested, but it was not found possible to detect the finer cracks due to the low density of the material and the necessity for using long wavelength radiation. Radiographic inspection was therefore considered necessary and by the use of a holder curved so that all struts were equidistant from the X-ray

target, it was found that 10 struts could be examined simultaneously. Owing to the low density of graphite, X-ray tubes fitted with beryllium windows operating at voltages in the region of 20-25 kVp were found to be necessary. The graphite must not be brought into contact with any metals and, as radiation of these low voltages is very easily absorbed, filtration in the form of plastic sheets between the specimen and the film must be extremely thin if the optimum flaw sensitivity is to be attained. Two radiographs at 90° are necessary and holders were designed with movable lead blocks so that after the first radiograph has been taken the struts could be rotated through 90° and the lead blocks moved laterally to uncover unexposed strips of film, and to cover the strips of film already exposed. It

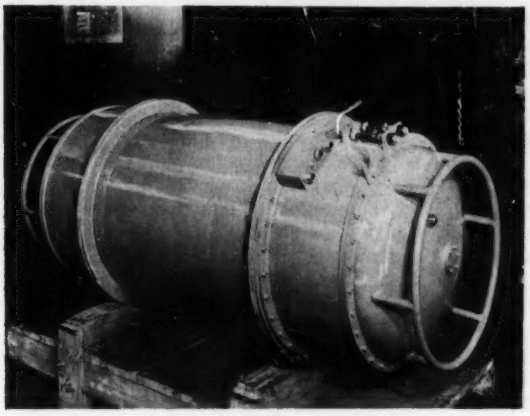


Fig. 3.—Tube head on 400 kV gas-insulated Pulsimax.

was thus possible to form the two images of each strut adjacent to one another. After radiography on films of a specially large size, the graphite struts are stored in quarantine until the radiographs have been examined and then those showing signs of cracks or other faults are rejected.

Reactor Vessels

Turning now to the examination of reactor shells, the problems confronting the radiographer are associated with site conditions and the size of the structure rather than with radiographic techniques. Many years have passed since the first use was made of radiographic inspection on a pressure vessel on an open site. One of the first cases on record was at Brunswick, in Germany, in 1932. A welded steam accumulator had failed on hydraulic test and it was decided to inspect the limits of the fracture by taking a series of radiographs. The somewhat primitive X-ray plant was carried piecemeal up ladders and assembled in a snowstorm on a narrow platform 30 ft. above the ground. Much to everyone's surprise, the equipment worked satisfactorily and radiographs were produced.

Slowly industry recognized the need for radiographic inspection of welded joints but very little use was made of this technique before the war. The impetus then given to industrial radiography led to the design of specialized equipment, but this was mostly used within the factories, and it was not easily transportable nor was it considered weatherproof.

Some companies had, however, acquired considerable experience in the manufacture and inspection of large pressure vessels on open sites such as oil refineries before the nuclear energy programme started. These concerns learned to grapple successfully with the problems of manipulating X-ray equipment under the most difficult conditions. The first reactor containers built at Windscale were relatively thin and no special difficulties arose. The consequences of the failure of the welded joints were, however, so much greater than usual that the utmost care was taken and only the best techniques used. Lead screens, fine grain films, rigid film processing conditions, accurate control of the kilovoltage and exposure, all combined to maintain a very high standard. Wire and stepwedge penetrameters 2% or less of the thickness of the parent metal were clearly depicted on every film and any sections showing marks of any kind were chipped out and rewelded.

The Calder Hall reactor shells were 2 in. thick and this entailed the use of 250 kV X-ray sets to keep exposure times within economical limits. Experience had already shown that high-voltage cables between X-ray tube and generator had a very high mortality rate in work of this type and, because of their greater reliability, equipments with the X-ray tube and transformer in the same tank were selected. Due to the inclusion of the high-voltage transformer the tube head for continuous operation at 250 kVp weighed about 10 cwt. and special supporting gear was therefore constructed (Fig. 1). One type of support was used on the hemispherical domes for the top and bottom of the reactor shell and another different type of support, generally similar to a jib crane, was used inside the reactor for the examination of the circumferential and longitudinal seams in the cylindrical portion of the shell (Fig. 2). These facilities enabled the tube heads to be rapidly positioned and no difficulty was found in keeping pace with the welders. The Chapelcross reactors were the same thickness and similar means were adopted for shell examination.

The commercial stations, Berkeley, Bradwell, Hinkley Point, Hunterston and now Trawsfynydd (N. Wales), having higher temperatures and pressures, entailed the use of thicker plate for reactor shells and heat exchangers. 250 kV X-ray sets were therefore inadequate and most of the constructors are using equipment capable of operation with voltages up to 400 kV. As several different concerns are involved, there has been the usual diversity of opinion as to the most suitable plant to utilize. Some manufacturers have chosen very large high-voltage generators which include the use of rectifiers and condensers connected by long lengths of high-voltage cable to the X-ray tube. The basic equipment is then heavy, but it is only necessary to move it at infrequent intervals, as the X-ray tube can be

Fig. 4.—Pulsimax in use inside reactor shell at Berkeley power station.

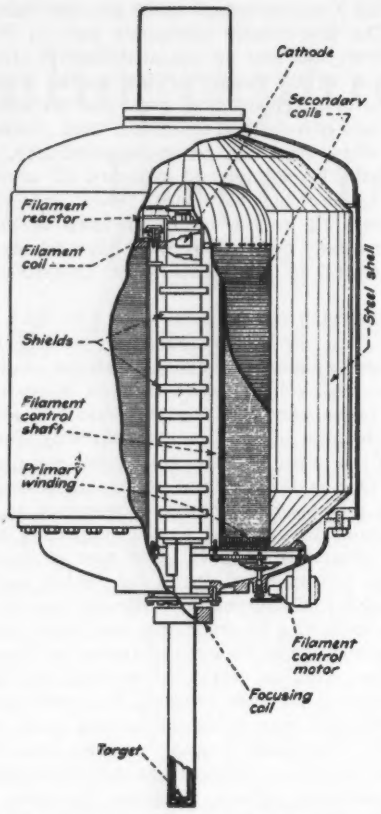


Fig. 5.—Section of 1,000 kV gas insulated resonance transformer and X-ray tube.

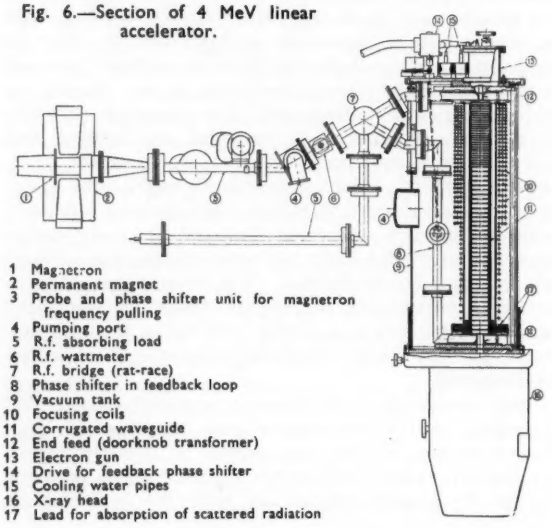
moved within a radius of 50 ft or more from the generator. Cables insulated for this voltage are both heavy and fragile so that manipulation of the tube head weighing six or seven hundredweights together with thick cables, is not easy, and specially designed supporting gear is necessary. As the weight of combined X-ray tube and high-voltage transformer, oil insulated for operation at this voltage, may be as much as 2 tons, Metropolitan-Vickers designed a novel unit utilizing a pulse transformer of a very low weight directly connected to an X-ray tube contained in the same tank, but with gas instead of oil insulation. The use of rectangular topped pulses of energy increases the intensity of the X-ray output. The use of the pulse transformer reduces the size and weight and a further reduction of the weight was brought about by the use of gas instead of oil as the insulating medium (Figs. 3 and 4). The tube head was connected to the modulator through small-diameter robust low-voltage cables 100 ft in length.

Exposures for 3-in. thick plate utilizing an X-ray tube operating at 400 kV vary from eight minutes up to 20 or 30 minutes, depending upon the speed of the film. For the best flaw sensitivity slow fine-grain films are desirable in order that the definition should be as good as possible. Still higher voltages are required unless the exposures are to become inordinately long where sections thicker than 3 in. are to be examined. This has become apparent on the reactor shells mentioned above, and other means for providing high energy radiation have therefore been sought. Conventional X-ray equipment at high voltages becomes extremely cumbersome, and a major problem is the distribution of the voltage uniformly along the X-ray tube and other highly stressed components. The General Electric Company of America many years ago designed an equipment for operation at 1,000,000 volts utilizing a resonance transformer with a multi-electrode coaxial tube in a tank with gas insulation (Fig. 5). This has proved extremely reliable and a great many of them are in use in static installations in factories. As the weight is only about 1,000 lb, this well-tried equipment could be utilized for examination of reactor shells 4 in. or 5 in. thick. The X-ray tube focus is 1 cm in diameter and to obtain the requisite definition distances of 6 or 7 ft would be necessary, but even at this distance the exposures would only be of the order of 3 or 4 minutes.

The linear accelerator developed by Metropolitan-Vickers for medical purposes has been in use for some years and has proved not only extremely reliable, but very inexpensive to operate. No glass insulated X-ray tube is employed and the all-metal accelerator tube can be extremely rigid in construction; it is thus well able to withstand the rough usage which must be expected under site conditions. Operating at 4 MeV, the industrial model has a focal spot of only 2 mm and can be employed at quite short distances without sacrificing the definition. On the other hand, owing to the very high output of radiation, even at appreciable distances, exposures are quite short, a factor which reduces the manipulating time. At a distance of 5 ft exposures of only 80 seconds are necessary for 4-in steel plate so that distances up to 15 or 20 ft may, if necessary, be used without exposures becoming protracted.

Another method of meeting this requirement is to use a multi-curie source of Co^{60}. A contractor actively engaged on the construction of the 4-in thick reactor shell for Latina, Italy, is utilizing a 1,000 curie Co^{60} source in a container manufactured by Metropolitan-Vickers (Fig. 7). Although the source is 2 cm in diameter, excellent definition is obtained at a distance of 12 ft. Exposures for plate of this thickness utilizing fine-grain film are only 15 minutes. As 4 or 5 ft of weld can be examined with a single exposure, this is a very economical unit. Several manufacturers have purchased containers of a similar type suitable for use with sources of 1,000, 1,500 and 2,000 curies of cobalt. The container, although it weighs only 35 cwt, is so well protected that the radiation intensity at the surface is at the tolerance level. No special precautions are therefore necessary when the container is not

Fig. 6.—Section of 4 MeV linear accelerator.



1 Magnetron
2 Permanent magnet
3 Probe and phase shifter unit for magnetron frequency pulling
4 Pumping port
5 R.f. absorbing load
6 R.f. wattmeter
7 R.f. bridge (rat-race)
8 Phase shifter in feedback loop
9 Vacuum tank
10 Focusing coils
11 Corrugated waveguide
12 End feed (doorknob transformer)
13 Electron gun
14 Drive for feedback phase shifter
15 Cooling water pipes
16 X-ray head
17 Lead for absorption of scattered radiation

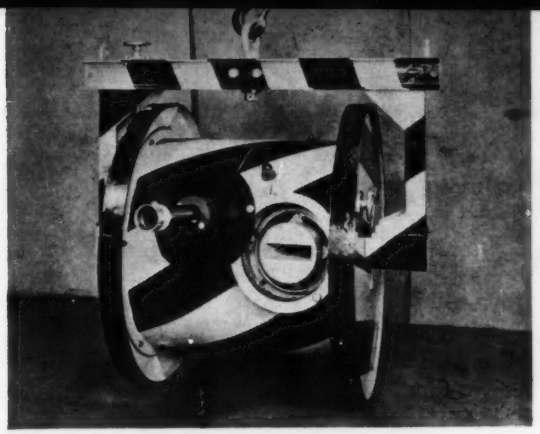


Fig. 7.—(Left) A 2,000 curie industrial cobalt container.

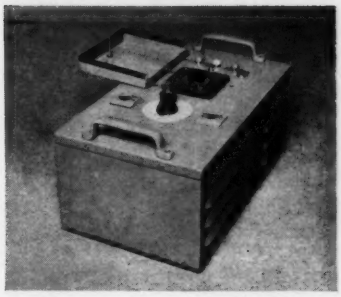


Fig. 8—(Right) Control box for 2,000 curie industrial cobalt container.

in use. As electricity is only used for control purposes, this source of radiation is independent of the supply conditions on site and radiographs of absolutely uniform density can be obtained without difficulty. A further advantage of the use of radioactive cobalt is that cooling is not required. A simple control box (Fig. 8), which may be 200 or more feet from the container, enables the operator to move the cobalt source into the exposure position by pressing a switch and, at the end of the pre-set exposure period, the source is automatically returned to the fully protected position. Should the electricity supply fail at any time during an exposure, the source returns automatically to the fully protected position.

The object of taking radiographs is, of course, to discover the presence of cavities of any shape or size in the welded joint. To indicate the quality of the technique employed, penetrameters are attached to the plate being examined on the side remote from the film. Many different penetrameters have been designed to give some indication of the size of cavity which one can expect to see on the radiograph. One type in general use has a succession of wires of known diameter, and this diameter is customarily expressed as a percentage of the thickness of the metal being examined. Another type is a small stepwedge, with holes in each step of the diameter equal to the thickness of the metal, and here again these are expressed as a percentage of the thickness of the metal being examined. Inspecting authorities in the past have specified that a 2% penetrameter of some specific type should be clearly visible on each film. Concerns manufacturing reactor shells have, however, endeavoured to use techniques which will show greater sensitivity and 1% is by no means uncommon. The cobalt sources mentioned above will show at the distance indicated 1% or less wire penetrameters. R. Halmshaw[1] has shown that a wire penetrameter of 0.65% can be resolved utilizing the linear accelerator where the focus is so much smaller in diameter than the Co^{60} source. Similar sensitivity could be obtained with cobalt but the source to film distances would have to be considerably increased resulting in protractical exposures. It would seem, therefore, that for reactor shells and heat exchangers up to 4 in. and 5 in. thick, cobalt sources could be used for the radiographic examination where a flaw sensitivity of 1% suffices. If reactor shells are to be built 6 in. thick, or if the maximum possible flaw discrimination is essential, then a linear accelerator will be the equipment of choice.

ACKNOWLEDGMENTS

The author wishes to thank the directors of Metropolitan-Vickers for their permission to publish this paper.

REFERENCES

[1] R. Halmshaw. *British Welding Journal*, October, 1959.

Lloyd's Examination Service

WHEN purchasing pressure plant the prospective owner often appoints an engineering firm of inspectors or engineering surveyors to supervise construction and certify the final product. This service is provided by several of the larger engineering insurance companies and also by Lloyd's Register of Shipping which, in recent years, has established a Land Division for this purpose. These organizations have established teams of engineers with specialist knowledge of pressure plant design, construction and testing.

So far as nuclear reactors are concerned, as with more conventional plant, such inspection services are made available to the ultimate owner on a fee basis. In nuclear, as in all pressure plant, engineering inspection begins with an evaluation of the design and this is particularly important in the case of primary circuits and containment vessels which do not, for various reasons, yield to treatment by the application of conventional codes.

At present Lloyd's Register has some 16 fully qualified engineers engaged full time on nuclear construction sites, which include Bradwell, Berkeley, Hunterston, AGR, Latina, and the land-based Dreadnought at Dounreay. In addition, surveyors attached to the various offices throughout the country are responsible for inspection at the steel works and in the manufacturers' shops. This staff is backed by the Land Division Headquarters department which is located at Norfolk House, Croydon, and the surveyors can therefore call upon a wide range of specialist advice when necessary.

Generally speaking, Lloyd's Register surveyors on a nuclear site rely on their extensive experience for the day-to-day agreement of quality during construction, the passing of radiographs, the testing of welders and the acceptance of procedure tests. In the event of a straightforward but serious difference of opinion between the surveyors and the contractors, both get in touch with their respective head offices to arrange a round table discussion on the site, although this is seldom necessary.

Although Lloyd's Register Land Division does not itself use non-destructive testing equipment as a general rule, it obviously performs a valuable service in checking all tests made whether they occur during rolling of the plate at the mill, during prefabrication in the main contractor's works or in the course of actual site construction.

After stress relief reactor vessels are invariably pressure tested and to date power station reactors have been tested with air as the testing medium. As an essential safety control during test and to obtain the fullest possible information, the Engineering Investigation Department of Lloyd's Register provides a strain gauging service and on a large reactor vessel several hundred gauges are used and strains converted to stresses during the course of the test.

Inspection of Nuclear Components

By A. F. GIFFORD, L.I.M., G.I.W.,
and B. J. LITTING, B.Sc.
(*International Combustion, Ltd.*)

To facilitate X-ray inspection in the works, International Combustion have built a concrete-lined pit in the main floor. The photograph shows a Pantak 400 kV unit examining a 2⅛-in.-thick circumferential seam.

Special provision for the non-destructive examination of heavy plant and heat exchanger elements has been made at International Combustion's Derby works. Current work concerns the testing of AGR boiler shells and elements.

IN order to cope with the considerable increase in radiographic inspection required by nuclear contracts International Combustion has had to widen the scope and increase the size of its radiographic department at the Derby works.

Prior to the company entering the nuclear industry, just over two years ago, the department consisted of three persons with one 250 kV X-ray unit and the usual isotope sources. It is now necessary to employ a staff of nearly 50—radiographers, film processing and administrative staff—to handle a throughput of approximately 3,000 films a week.

At Derby, nuclear welding is subjected to 100% radiographic inspection where practicable. When access is inadequate, alternative methods of non-destructive examination are applied. The volume of work in hand at present necessitates continuous coverage in the form of day and night shifts.

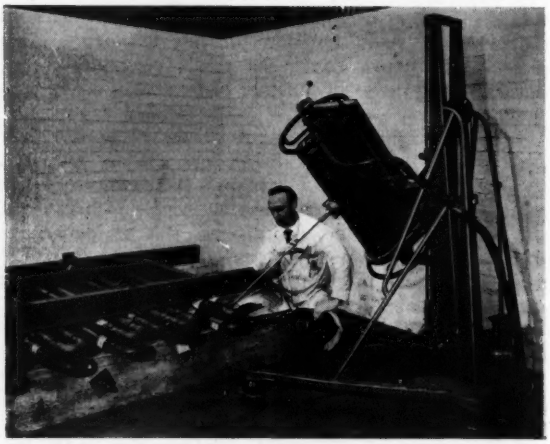
The demand for inspection of welds in thick material such as heat exchanger shells has meant that more powerful equipment has had to be obtained. Three 400 kV sets are now available as a critical inspection of 3-in. steel plate requires an exposure of 380 kV. This increase in power has in turn increased operational hazards and protection of personnel has been a major factor in the works. To lessen the risk, radiography is carried out in a concrete-lined pit.

In addition to heavy plate inspection, five X-ray sets of up to 260 kV are continuously engaged on other types of work, mainly of a nuclear nature. By far the greatest amount of work undertaken by these five units has been in connection with butt joints (2-in. o/d) and bifurcation welds on superheater, evaporator and economizer tube banks for the AGR heat exchangers. The chrome-molybdenum superheater tubes in particular call for a very critical inspection and this has entailed the checking of argon arc root runs before completion of welding with metallic arc. In this intermediate stage it is then possible to rectify any defective roots: this would be an extremely difficult operation after the final welding. On all the tube element welds the company has had to devise special techniques to carry out the 100% critical inspection required and small portable X-ray units have been essential. The AGR contract involving four heat exchangers is expected to require a total of 40,000 films for the tube banks alone.

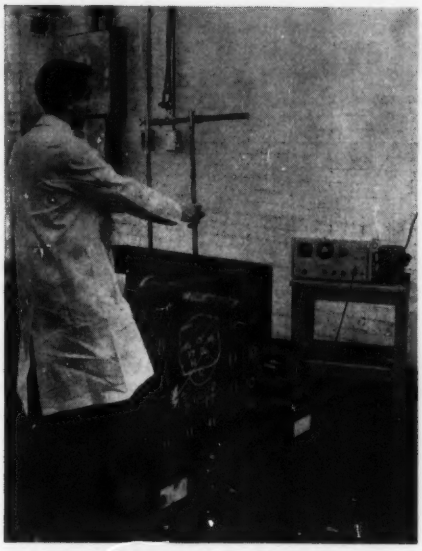
An unusual aspect of work in connection with nuclear projects has been the checking of thick grey iron castings required for biological shielding. For these castings the maximum porosity has been specified at 3% and since normal gamma radiography would be impracticable the department has developed a special scintillation counter technique. In this method the casting is scanned using a low activity Cobalt-60 source of radiation and a highly sensitive scintillation counter (sodium iodide crystal, thallium activated) to record the dose rate on the far side of the casting. The readings obtained are plotted on grid graphs. Faulty castings are subsequently repaired and re-checked.

For plate thicknesses above 3½ in. the department has ordered a 1,500 curie source of Co^{60} complete with remote control exposure container. Ultrasonics are also extensively used.

The heat exchanger shell plates, after straightening and descaling at the steel mill, are ultrasonically tested for laminations using a Solus-Schall Mk 9 set in conjunction with a plate roller and monitoring equipment. The plates are scanned on a 12-in. grid, offset 6 in. on the opposite side and all defects are plotted on a sketch of the plate. Consideration is given to the location of defects prior to



X-ray examination of chrome-molybdenum tube welds using a Solus-Schall 260 kV unit.



(Left) Inspecting a transport cask outer casing by the scintillation counter technique.

(Right) Magnetic inspection of thermal sleeve welds.

acceptance of the plate and efforts are made to ensure that any defects are included in cut-outs from the plate when this is possible.

On arrival at Derby the edge preparations are machined for the longitudinal and circumferential welds and magnetic crack detection of the preparation is carried out using either large permanent magnets across the plate thickness or a transportable magnetic unit with hand probes. Black magnetic ink is normally employed for this purpose: where it has been necessary to crack detect a flame cut edge, red ink has been found to give far better results.

The plates are bent to the required radius and welded by the submerged arc process. The nozzle and branch openings are then made by boring and are checked for laminations using large permanent magnets and black ink. The nozzle welds are checked with a Solus-Schall KRH.4D power unit (4,000 amp), a coil being wound round the nozzle which is then sprayed with magnetic ink from a pressurized container and inspected. Any defects revealed by this method are repaired and then rechecked before releasing the vessel.

Where fillet welds such as flanges and so on are involved which cannot be checked by radiography, the weld is examined by use of dye penetrant since this has been found more convenient for shop operation.

The thermal sleeves are checked prior to welding, on a Magna-flux unit, and a standard has been established whereby the degree of acceptable defects in different parts of the sleeve is varied according to location. All sleeves are inspected and stamped by the inspector.

Turning now to heat exchanger element production a 100% check has been carried out on 2¼ Cr/1 Mo cold bent return bends to ensure that excessive thinning has not occurred on the outer portion of the bend. The Solus-Schall ultrasonic thickness gauge is used for this purpose and a jig is employed to ensure that the exact area required is tested each time. It has been found necessary to employ a 10 mm 6 Mc probe to ensure consistent results. Continual checks are made against standard blocks to maintain the calibration of the instrument.

Although all welded bifurcations are checked by 100% radiography, as an additional precaution magnetic testing is carried out in the crutch of the weld using a Radalloyd portable magnetic unit and red ink.

Ultrasonic inspection of the plates has proved very satisfactory, only very minor defects having been detected on subsequent magnetic inspection. The need for such close checking of openings has not proved to be really necessary and it must be assumed that the standard employed ensured a clean plate. It has been noted during testing that a plate is generally either clean or very dirty.

Some difficulty was found in establishing a satisfactory ultrasonic standard because a specification established to eliminate lamellar inclusions did not preclude the use of plate containing many smaller inclusions at various levels throughout the plate, which, apart from the possibility of welding troubles, considerably weakens the plate. The desirability of a British Standard for ultrasonic inspection of plate for various classes of pressure vessel is becoming more and more apparent.

A very important aspect of International Combustion's whole non-destructive testing programme has been the assistance given in training welders up to nuclear standards, by the radiographic examination of their various test plates and by ensuring that the necessary high standard is maintained in production.

Ultrasonic examination of plate intended for boiler shell fabrication at International Combustion's works.

Testing Graphite Struts

By I N. BEECH
(Head of Laboratories, Powell Duffryn Carbon Products, Ltd.)

Struts are loaded ten at a time into the X-ray cabinet incorporated in the production line at Hayes.

X-radiography is being used for a 100% check of the graphite fuel element struts for Berkeley. Over 200,000 struts—each 24 in. by 1 in. by 1 in.—are being examined on a production basis.

GRAPHITE struts are an integral part of the fuel element design at Berkeley. The vertically stacked uranium elements are individually supported by pairs of graphite struts which are located in guides in the fuel channels of the graphite moderator. These struts must have adequate strength to withstand light static loads and stand up to shock loads which may occur during reactor charging and discharging. Theoretical calculations showed that there was a comfortable safety factor as regards static loading, but after a consideration of the large variation in mechanical properties of the material and the occurrence of flaws in the moderator bricks from which the struts were to be machined—which could be very serious in the case of the more complicated geometry of the graphite struts cut from the larger blocks—it was decided to investigate how to introduce a 100% non-destructive test.

Proof loading, ultrasonics, eddy currents, and radiography were all considered. The Atomic Energy Authority, in conjunction with the designers of the fuel element assembly (A.E.I.-John Thompson) finally agreed that radiography was the answer. Powell Duffryn Carbon Products were awarded the contract for the supply of the struts, including a 100% inspection by radiography.

The following sections describe the non-destructive test unit installed at the Hayes factory and illustrate some of the findings. Two principles were established which had an important bearing on the X-ray technique used. The first was that the nature of graphite (being a low-density element) made it necessary to use an X-ray tube capable of a high proportion of long-wave or soft radiation.

The second was that the ease of detection of certain flaws in graphite depends upon the orientation of the flaw with respect to the direction of the X-ray beam. Flaws in graphite tend to be of a laminar nature due to the anisotropy of the material. The original particles of the petroleum coke grist used in the manufacture of graphite tend to have a *preferred* orientation in the resulting material, depending upon the technique used in forming, i.e., extrusion. The result is that, whereas it is possible to detect a flaw in graphite by radiography using one *favourable* direction of the X-ray beam, the same flaw may not be detected from a radiograph taken at, say, 90° to the first exposure.

In order to study more closely the effect of the orientation of a flaw relative to the incident X-ray beam, Powell Duffryn's laboratory conducted an experimental investigation during which 16 exposures were taken of a typical flaw in a 1-in. by 1-in. section of graphite.

A composite test specimen was employed in order to achieve the desired change in flaw orientation. The first part comprised a ½-in. diameter graphite rod containing natural cracks which ran approximately along a diameter for the whole length of the rod. The second part was an *unflawed* piece of 1-in. by 1-in. section, with a ½-in. diameter hole at its centre. The first flawed piece was machined so that it was a tight fit in the 1-in. by 1-in. section.

The crack in the rod was indexed against the second part so that it was parallel to the incident X-ray beam (i.e., the crack was the "preferred" direction). An exposure was taken and then the flawed rod turned through 22½° after each shot. After 16 exposures the crack was turned 360°. The experiment showed that for any two orientations selected at right angles, the corresponding paired radiographs indicate the presence of a crack. In the case approximating to the 45° shots the flaw was not clearly defined on both of the paired 90° radiographs.

From the above experiment it is concluded that if paired radiographs taken at right angles are used for the inspection of graphite components, then any *slight* indication of a flaw on either radiograph could indicate the existence of a serious flaw at a 45° orientation (or thereabouts). In view of this a rigorous standard of inspection was recommended for radiography—the slight indication of flaws warrants the rejection of the component: alternatively, it is referred for a further investigation.

The X-ray installation, which was supplied by Inspection Equipment, will now be described in detail. The design problem was to radiograph some 200,000 components being produced at a rate of one every 30 seconds. The U.S. Machlett OEG/50A X-ray tube, which gives high-intensity long waves, was selected: the output is 50 kV. This is made possible by the use of a thin beryllium window which is part of the tube envelope and is the only element of inherent filtration. The use of this type of radiation for graphite inspection enables high-contrast radiography to be obtained.

One of the first points to establish accurately was an exposure chart for graphite. At 20 kV an exposure time of the order of 10 minutes was required, whereas at 25 kV the exposure was of the order of 80 seconds. In the latter

case the sensitivity was 0.5-1.0%, and it was thus not necessary to use extended exposure times. This work showed that one X-ray unit would satisfy existing production providing the complete installation was automated and integrated with the production line.

The graphite components, of overall dimensions 24 in. by 1 in. by 1 in., are accommodated 10 at a time in special exposure trays. Two images of each component are obtained, the second being shot on the same film after each component has been turned through 90°. In order to radiograph the complete components 10 at a time, an extra large size film of 24 in. by 24 in. is used. If a radiograph of a particular section of the components is required then 24-in. by 2-in. film is utilized. After considerable research Kodak Crystallex fine-grain film was finally selected. Envelope-packed film is slid into the curved base of the exposure tray, and the graphite components are held in a lead-free masking rack which is curved similarly to the exposure tray base. Automatic component identification is built into the exposure tray so that any defective graphite piece can be easily withdrawn from the production line.

The location of the components and film relative to the beam of radiation was carefully investigated. It was expected that this would be one of the critical factors when using such a large film area due to the "heel" effect which is inherent in X-ray tubes.

Optimum film location was achieved for obtaining uniform film density after an extensive investigation into the distribution of radiation from the tube. To assess sensitivity and establish a satisfactory technique a special set of graphite penetrameters were made. These were in the form of stepwedges machined to very fine limits. A radiographic technique was worked out which gave a 1% sensitivity on the production line. With 1-in. thick graphite, defects representing a thickness difference of one-hundredth of an inch can be seen on the radiograph.

After taking the radiograph the unusually large film is automatically processed by a machine manufactured by the Danish company Refrema of Roskilde. This unit carries out the complete processing of the film without the need of attention from the dark-room staff. As the films are untouched by hand, scratches and fingermarks are avoided. Also, variations in results which are inevitable with hand processing are eliminated. The machine is composed of two main sections, processing and drying. The processing section is located in a "safe-light" dark room where loading, developing, fixing and washing are carried out. The drier is in full light in the viewing room, where the films are inspected. A light trap is located in the wall between the dark and light rooms.

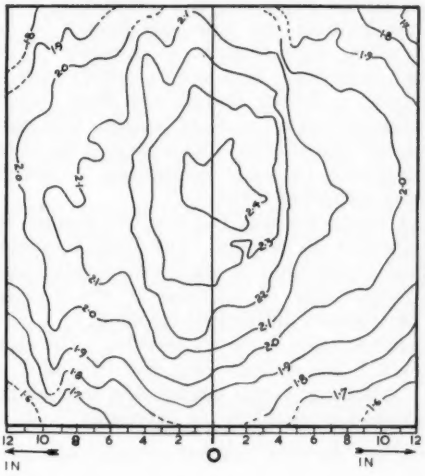
The films are loaded on hangers and from this point onwards until the finished films are dried and ready for viewing the process is fully automatic. The mechanism lifts the films up and lowers them into the developer, rinses, fixes, and washes by means of electrically driven endless chains. The films are agitated not only in the developer but also in the fixer and wash, so that flow marks and air bubbles are avoided.

To maintain the solution at a constant and even temperature throughout the developer, a circulating system is provided. Solution is drawn into a small tank by an impeller which pumps it past an immersion heater and cooling coil, which are controlled through a magnetic valve by a contact thermometer. After being heated or cooled, the solution is returned to the main developing tank. The entire contents of the tank are circulated through this system continuously.

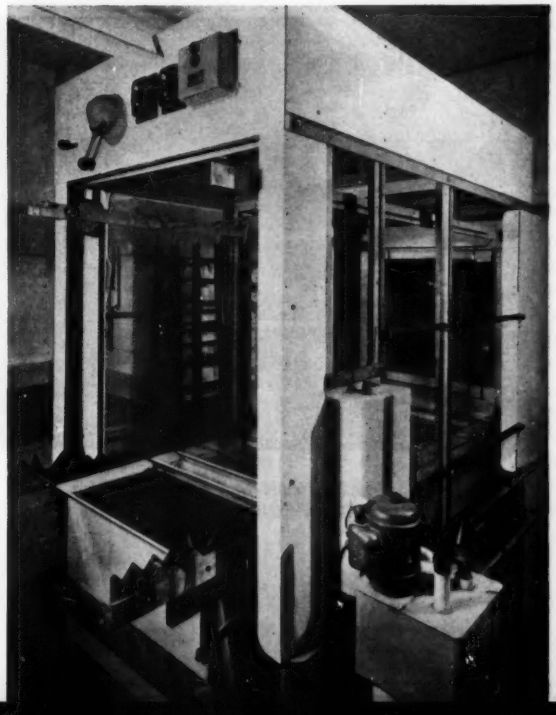
The cycle of the machine is set in accordance with film manufacturers' recommended times and temperature, but this may be modified through a regulator. Normally, with the gear set to give the shortest times, a film is ready for wet viewing in approximately 10 minutes. The time in each bath may be further varied independently by changing the notches carrying the hangers.

From the storage space in the drying machine, the films are mounted one at a time on a specially designed 24-in. by 24-in. viewer. This was designed for optimum viewing sensitivity of each component on the film. A sliding front panel carrying the radiograph is drawn from side to side across a fluorescent light source which is screened so that only the two views of one component are illuminated at a time. This gives the best viewing conditions and it enables the inspector to concentrate on one component without distraction from the rest of the radiograph.

It has been shown with respect to these particular graphite components that the critical regions for inspection are the ends of the component and that the most serious flaws in the body of the strut are those of a cross-grain nature. Work is still proceeding on the interpretation of flaws by radiography and the correlation with other properties of the graphite.



(Left) X-ray density contours for 24-in. by 24-in. film.



(Right) Fully-automatic film processing unit installed by Powell Duffryn specifically to handle the radiography of graphite struts.

Leak Detection

By W. STECKELMACHER, B.Sc.
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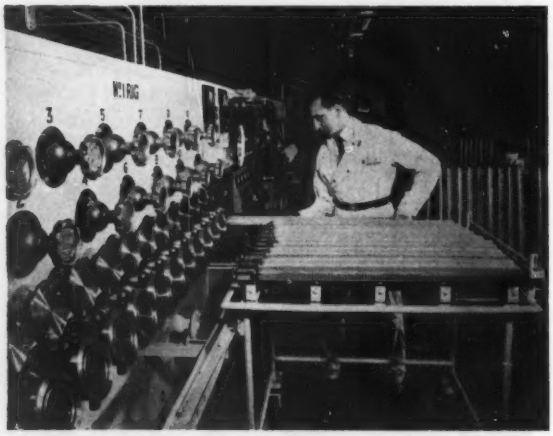
in collaboration with *Nuclear Engineering*.

To provide a final check on pressure- or vacuum-tightness a wide range of leak-detection systems has been developed. This article describes a number of methods which have been successfully used for the examination of nuclear equipment.

GENERALLY speaking, non-destructive examination aims at testing the strength of bulk material and joints by checking grain structure and density, thickness, presence of voids, inclusions and surface defects such as flaws and cracks. In the greater part of these test methods, evaluation is indirect: the quantities measured have to be properly correlated to the serviceability characteristics of the material in question, and thus the uses of these methods depend on the interpretation of the test results. Leak-testing procedures, on the other hand, facilitate direct evaluation: the quantity measured represents in itself the physical effect of a faulty condition and thus requires no further analysis for practical assessment.

Leak-testing in the modern sense is concerned with the determination of the rate at which a liquid or gas will penetrate from anywhere within a "tight" component or assembly to without or vice versa, as the result of a pressure differential between the two regions. This leak rate serves as a direct yardstick for the conditions to be expected in service.

Aiming at absolute leak-tightness is an academic endeavour. In practice, all that can be asked for is a degree of tightness more or less stringent according to the application. For the purposes of measurement, tightness is expressed in terms of gas-tightness. The standard chosen is the (gas) mass flow rate into, or out of, a vessel due to leakage, and the unit now generally accepted is the leak allowing a gas mass flow rate which causes a pressure rise of 1 micron Hg per second in a volume of 1 litre=1 lusec. A clusec is 1/1,000th of a lusec. Engineers may be more used to expressing mass flow rates in other units, e.g., in terms of cubic centimetres of gas (at n.t.p.) per minute and the equivalent quantity in lusecs is 1 c.c/min (n.t.p.)=12.67 lusecs. In order to illustrate the magnitudes involved, the following example[1] is given: A gas-storage tank at 6 lb/in.^{2} gauge pressure has a leak of 1 lusec. This corresponds to a seepage of gas at the rate of about 1.3 mm^3/sec (n.t.p.). If the leakage were only 0.1 clusec, the loss of gas at n.t.p. would be about 40 c.c/year.



At the AEA's fuel element works at Springfields each element casing is helium tested.

The Need for Vacuum Leak-testing Standards

Leak-tightness as a requirement, although prominently associated with the operation of high vacuum apparatus or systems (which, of course, have a wide application in the field of nuclear physics and engineering, for instance, particle accelerators) is not restricted to such equipment. Leak-tightness is, in fact, imperative in innumerable cases where components and assemblies are designed to operate under moderately reduced pressure only, or at atmosphere, or in a pressurized condition.

For example, diffusion plant for the separation of U^{235} works in part at a moderately reduced pressure and in part at positive pressure. Moisture leaking-in would lead to the decomposition of the process gas according to the reaction

$$UF_6 + 2H_2O \rightarrow UO_2F_2 + 4HF$$

and gas leaking-out would constitute a health hazard and substantial loss. For that reason, the Capenhurst plant,[2] for a while the largest low-pressure system existing in Western Europe, comprising pipework of the order of 100 miles, valves approaching the number of 10,000 and joints (welded or otherwise) totalling 100,000, was leak-tested throughout to high vacuum standards.

Liquid-metal heat-exchanger circuits, such as sodium loops, operate at atmospheric pressure. However, temperatures are maintained up to 600°C and the construction materials associated with the loops (such as zirconium and niobium) are liable to corrosion by a sodium oxide concentration as small as 10 ppm.

Hot water exposed to radiation is highly corrosive owing to the large amount of dissolved hydrogen and oxygen present. Test rigs built for the investigation of associated corrosion phenomena are constructed to high vacuum specifications in order to facilitate proper measurement and control of the gas evolution and content. Pressurized test rigs have been built for the testing of fuel-element sheaths simulating the conditions in a pressurized water reactor in order to trace any holes and fissures in the jackets which would allow moisture to penetrate to the uranium charge, in service. As is known, certain types of fuel element carry a helium charge, and these require testing as a safeguard against outward leakage. Generally speaking, it appears that the lusec-clusec range is the order of leakage magnitude for most components or assemblies of the kind mentioned above.

Broadly, leak-testing methods fall into two groups: (a) positive pressure and (b) vacuum. The latter invariably uses atmosphere as one limit of the pressure differential, whereas the former may be operated at any pressure differential. The pressure differentials employed in a positive pressure method must be clearly specified. The same hole, tested by the two methods, will give two different leakage rates. Assuming viscous laminar flow through the hole, the two rates are related by the expression

$$L_p = (P^2-1)\,L_o$$

where L_p is the leakage rate at positive pressure P (in atmospheres) and L_o is the vacuum leakage rate.

Leak-hunting—the location of leaks in a component or assembly—is time-consuming. A small and simple component or assembly of, say, 1 litre volume may take as much as one hour. More complicated assemblies of the size of the Zeta torus may take several days. The magnitude of the task is best illustrated by quoting the figures stated recently for the Capenhurst laboratories[2] where, in connection with work not associated with the diffusion plant, components are vacuum-tested at a rate of 20,000 per year.

In order to make certain that a piece of equipment is suitable for a given purpose, a degree of leak-tightness has to be specified, consistent with the proposed application. If the proving test indicates excessive leakage, the leak or leaks must be found and repaired. Thus, in the modern sense, leak location tests are essentially applied to what may be termed " initial rejects " and, in actual fact, form part of the rectification procedure.

Some test methods are suitable only for leak proving; others, in particular the search gas methods, may be used for proving *and*, if required, subsequent leak location by a simple extension of the same operational principles.

Testing to specification presupposes the existence of ready means for checking the accuracy of the test results. However, a number of factors, influencing test results, are undetermined and are liable to change from test to test, such as the sensitivity of the leak detector and, in certain cases, conditions specific to the object under test. Therefore, in practice, to arrive at accurate results quantitatively, a calibrated reference leak is attached to the plant in a position equivalent to that of the tested vessel. This facilitates comparison of the response from the tested vessel with that obtained from a known leak under the conditions prevailing while the test is in progress.

VACUUM TEST METHODS

The most sensitive of all the leak-detection instruments is the mass spectrometer. This instrument does not depend for its operation on pressure differentials but separates, and indicates the mass of, the ions formed by the test gas and the ions formed by the residual gases passed in from the vacuum system. Helium is the preferred test gas. The instrument is capable of detecting leakage rates of less than 10^{-6} lusecs.

The mass spectrometer operates in the pressure range 0.01-10 micron Hg, produced and maintained by its own vacuum pump. If the volume of the vessel or system to be tested is large, the small pumping speed available would cause the response and recovery times to be excessively long. This can be overcome by employing a high-speed diffusion pump as the additional pump in the system to be tested and transferring the mass spectrometer leak detector input connection to the backing side of that pump. In this position advantage is taken of the accumulation of gas (including test gas) on the backing side of the pump resulting in a reasonable response time.

A variation of the conventional mass spectrometer leak-testing method has been described recently as applied to the testing of fuel element jackets for tightness with respect to hot pressurized water potentially penetrating to the fuel proper when put into service.[3] The fuel elements were soaked for two minutes in a helium pressurizing vessel maintained at 50 p.s.i., then transferred to the chamber of a portable mass spectrometer leak detector and the chamber evacuated to a pressure of 150 micron Hg. At this stage the throttle valve on the leak detector was gradually opened,

Fuel elements at Springfields being filled with helium prior to leak detection.

holding the pressure in the inlet of the mass spectrometer at 0.1 micron Hg. The relative quantity of helium passed into the instrument was then read off the indicator in the usual way. The " response " was taken to be the maximum reading obtained while the inlet of the mass spectrometer was at the aforementioned pressure.

The elements were tested in batches of 10 and a total of 200 could be examined per hour with one instrument, by this method. The following table is an example of a typical result of a test on 120 fuel elements. Those with a high " relative response " were subsequently exposed to hot water (at 150°C and 75 p.s.i. pressure) in a special autoclave, made from glass for visual observation. In one instance, an element with a relative response of 35 (3=100) gave first indications of impending failure 9 hours after the start of the hot water test, and finally ruptured after a total of 22½ hours.

Table I.—Leak Testing of Fuel Elements

Range of Response	Number of Fuel Elements in Range
0 to 0.5	64
0.6 to 1.0	23
1.1 to 1.5	15
1.6 to 2.0	12
2.1 to 3.0	6
3.0	0
Total No. elements tested	120

The mass spectrometer leak detector is a complicated instrument, requires highly skilled servicing and is expensive both as an investment and in operation. There is room, therefore, for the application of other methods of investigation.

Palladium Barrier Leak Detector. The nearest to the mass spectrometer method in sensitivity is the palladium barrier leak detector. This method employs hydrogen as the search gas and a hot ionization gauge as the sensing element. The gauge is sealed off from the rest of the system by a barrier of palladium which, when hot, is permeable to hydrogen only, the palladium disc constituting the anode in the arrangement, heated by electron bombardment from an indirectly heated cathode. The instrument can detect leaks of the order of 10^{-5} lusecs in exceptional cases, and its success is essentially based on the selective permeability of the palladium, facilitating

Bradwell boiler elements being checked at Clarke Chapman's works. Each evacuated element is surrounded in a hydrogen atmosphere. Leaks into the system are detected by an Edwards palladium leak detector.

the establishment of equilibrium with a far lower level of pressure fluctuations than is normally obtainable in practice. At the same time, the provision of the palladium barrier serves as a protection for the ionization gauge, reducing the effect of the pressure limitation and making it possible to connect the instrument to the backing side of the system.

However, some disadvantages attach to this method, in particular the fact that the hot palladium will catalytically oxidize hydrogen in the presence of excess oxygen, but this can be overcome by taking certain precautions.

Oxygen Leak Detector. This method, coming into the same range of sensitivity as the previous type, has been used at AERE, Harwell. The operating principle is based on the fact that the presence of oxygen in a diode causes a decay of the electron emission from the cathode. In the particular design[4], a normal ionization gauge is converted into a diode by an auxiliary power pack to be operated in conjunction with a standard ionization control unit. On penetration of oxygen into the vessel under test, the changes in emission serve to indicate the presence of a leak.

A major handicap of this method is the pressure limitation of the gauge. This makes it imperative to connect the detector to the high vacuum side.

Hydrogen-Pirani Method. The technique is frequently used in the testing of dynamic systems and is suitable for the detection of leaks of 1 clusec magnitude. As is the case with all leak detectors which employ a Pirani gauge as sensing element, it is connected to the backing side of the system because, by the nature of the gauge, sensitivity conditions are poor when operated on the high vacuum side.

In practice, the method suffers from the disadvantage that this type of gauge responds to changes in total pressure, i.e., to pressure fluctuations in the system generally, whether they are due to outgassing, pumping speed fluctuations, or the evolution of gases in the pump oils, etc.

Differential Pirani Gauge Method. The objections raised in connection with the preceding method can be overcome to a certain extent by employing the principle of differential measurement. Two Pirani gauges are connected in parallel to the system under test but one is used with a chemical absorbent (of the test gas) interposed between the gauge and the system; thus, one gauge is exposed to both test gas and standing air pressure and the other (in line with the trap) to standing air pressure only. The minimum leak detectable is of the order of one magnitude better than that of the foregoing method.

The method is not altogether successful, at least as far as Pirani gauges are concerned, mainly for the reason that no wholly satisfactory combination of test gas-absorbent can be found. Carbon dioxide and calcium hydroxide respectively are used in one version of the method. Better results are reported for ionization gauges employed in this fashion.

Charcoal-Pirani Method. Another variant of the Pirani gauge leak detector is the Charcoal-Pirani method. This method, frequently employed in the establishments of the Industrial Group of AEA, is simpler than the differential arrangement in that only one gauge is used. The gauge, situated in a loop, appropriately valved and connected to the pumping line of the system in the interspace of two diffusion pumps in series, is itself in series with a charcoal trap which is cooled by liquid nitrogen or, alternatively, by carbon dioxide. The search gas is hydrogen. Charcoal maintained at the low temperatures mentioned is known to absorb this gas less readily than any other gas with the exception of helium. The actual proportion of hydrogen and air absorbed by the charcoal depends on the effective temperature of the charcoal and, in addition, for a given arrangement, on the flow rate of the gases passing through the trap. In practice this means that the high sensitivity required when only small leaks are acceptable, is obtained by cooling with carbon dioxide, whereas in the case when larger leaks are permissible, cooling is effected with liquid nitrogen. The smallest leak detectable by this method is in the range of 0.1-0.01 clusecs.

Halide Diode Detector. This is a development of the halide leak detectors, first used for positive pressure testing (see below). This method makes use of the phenomenon of positive ion emission from a heated platinum anode in the presence of traces of organic halide. For the purposes of leak-testing, a platinum diode with the anode heated to about 800°C is placed within the system to be tested. The sensitivity of the method lies in the range of 10^{-2} to 10^{-3} lusecs.

A drawback of the method is the possible sudden loss of sensitivity, especially after exposure to high concentrations of halide vapours, but successful methods of reactivation are known.

Infra-Red Absorption Method. The method is based on the use of an infra-red gas analyser which facilitates detection of gases with a clear absorption band in the infra-red spectrum, in a mixture, by comparison with the absorption characteristics of a pure standard sample of the same gas. The probe gas normally used is nitrous oxide. Leakages of the order of 10^{-3} lusecs may be detected by this method.

The procedures described so far are the most popular in the nuclear field where tightness to fine limits is required. The methods use exclusively reduced pressure and are of the dynamic type. They are invariably suitable for proving *and* leak-location testing.

The static methods available are few, at least in the sense of tests operated exclusively at reduced pressure.

Pressure Rise Method. This is the simplest of the static tests. It provides for the part of the system under test to be sealed off after evacuation except for a communication with a vacuum gauge, whereupon the rate of pressure rise is noted. The method is of considerable importance where testing aims at comparatively coarse leaks, but is unsuitable

for routine leak-hunting. Its main drawback is the difficulty of distinguishing between the various possible causes of the pressure rise, such as "virtual" leaks, outgassing, etc.

Hood Method. This is a variation of the pressure rise method which overcomes the difficulties just mentioned. A hood is placed over the component to be tested and both the space within the component as well as that under the hood are evacuated. During pumping the leaks are not effective, as the pressure is the same within and without the component. After pumping down and isolating, atmospheric pressure is admitted to either the space under the hood or the inside of the component and as a result leakages can be detected, if present, by comparing the pressure rise using a suitable pressure gauge.

POSITIVE PRESSURE METHODS

Although vacuum test methods are meeting present-day requirements so far as sensitivity and accuracy are concerned, they have certain inherent deficiencies from the user's point of view. Such criticism concentrates essentially on the following points: (a) The nature of some of the leaks involving a long and tortuous flow path, makes them liable to remain undetected, unless, when it comes to location testing, examination is conducted at a slow enough pace. (b) Some of the equipment which requires testing has pronounced shapes and forms, such as heat exchangers for instance, making testing by vacuum methods cumbersome and (c) the vacuum testing plant itself is intricate and this may complicate actual test procedure.

Thus a number of testing methods have been evolved which employ positive pressure and offer essentially the advantage of comparatively simple equipment, requiring less delicate handling when in use. A great number of these methods are based on ad-hoc pressurizing of the equipment to be tested, as will be seen from the following brief review, dealing with proving methods first:—

Pressure Drop Method. The component or assembly to be tested is pressurized and outward leakage measured by the fall in pressure. The rate of pressure fall determines the leakage rate.

Volumetric Displacement Method. The component or assembly to be tested is pressurized and the leakage rate measured with the help of a flowmeter inserted in a line connecting the part with a source of constant pressure.

Search Gas Methods. Some of the search gas methods, primarily developed for leak location testing (see below) can be adapted for proving tests. The equipment to be tested is pressurized and placed under a hood. Samples of the atmosphere under the hood are collected by a sampling probe, sometimes called the "sniffer," and made to pass over the detector element. The infra-red absorption method, mentioned in the section on vacuum methods, can be readily adapted for the successful leak proving of pressurized equipment.

The most important methods, suitable for leak-location testing in the first place, are the following:—

Bubble Method. The component is pressurized with air and immersed in water. The presence of leaks is indicated by the formation of bubbles on the component surface. The method is slow where the leaks are small, but other gas-liquid combinations can improve the sensitivity. A variant of this test avoids immersion of the part to be tested in a bath by painting the surface of the component with soap solution.

Halide Torch Method. The method was originally developed with the object of tracing halide vapour leaks issuing into atmosphere from pressurized refrigerator systems. A Primus-type blow torch is fitted with an air-intake via a length of flexible metal tubing, the torch normally burning with a non-luminous flame. In the presence of organic halide vapours the colour of the flame changes to green and, as the concentration of halide vapours increases, the flame turns bright blue. Leaks down to 2 lusecs can be detected by a skilled operator.

The *Halide Diode Detector*, described in the section on vacuum methods, can be employed for leak-location testing by the positive pressure method but, in order to facilitate proper collection of the sample, a small pump is built into the probe. The *Infra-Red Absorption* method is also suitable for leak-location testing but the construction of the sensing element is fairly complex and a relatively long flexible sampling probe line has to be used. This adversely affects the response time at maximum sensitivity. Leaks of the order of 4×10^{-2} lusecs can be detected.

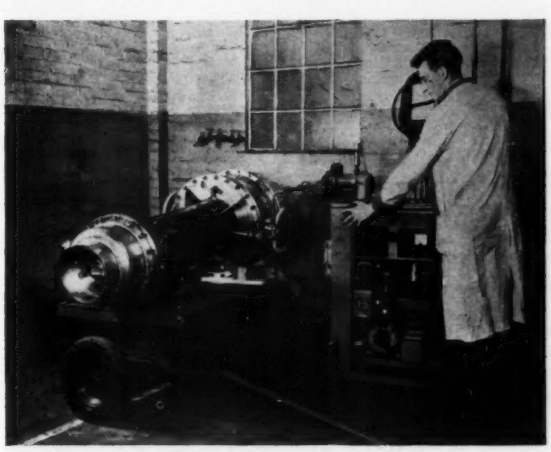
Thermal Conductivity Detector. The operational principle is similar to that of thermal conductivity vacuum gauges. The resistance of a hot-wire element, normally exposed to air, changes in the presence of traces of the search gas. The instrument gives a good response when hydrogen is used as the probe gas. Leaks of the order of 10^{-1} lusec can be detected.

Mass Spectrometer Method. Mass spectrometer leak detectors are most sensitive for leak-testing of evacuated equipment but may also be used for leak location in pressurized equipment. Gas samples are passed through the ion source at the mass spectrometer inlet by means of a length of flexible vacuum hose containing a small adjustable or fixed leak at the collecting end. Leaks as small as 7.5×10^{-4} lusecs can be detected with this instrument.

Positive pressure methods may be criticized, if applied to equipment intended to be operated at reduced pressure because of the inverse pressure differential resulting in a mechanical stress opposed to that for which it was designed. This will cause leaks to open (or close, as the case may be) under certain conditions. However, there are instances, of course, where the same argument applies vice versa with respect to vacuum test methods.

REFERENCES

1. Cross, S. H., and Steckelmacher, W., *Research*, May, 1956, 124-131.
2. Kronberger, H., *Proc.I.Mech.E.*, 172 (1958), No. 3.
3. Barnes, A. H., Smith, F. A., and Wimunc, E. A., *Symposium on Non-Destructive Tests in the Field of Nuclear Energy* (Am. Soc. Test. Materials, 1958).
4. Barton, R. S., *U.K. AEA Report No.* AERE GP/M 189, (1956).



Leak detection applied to a glandless pump manufactured by Hayward Tyler and Co., Ltd., using Edwards equipment.

Unconventional Methods

By J. COLE, M.Sc.
(*Fulmer Research Institute*)

ALTHOUGH a certain amount of conventional non-destructive testing is carried out at **Fulmer Research Institute,** it is a comparatively minor activity. The Institute does, however, make use of a number of techniques which may be regarded as rather unconventional forms of non-destructive testing.

Corrosion Damage

First, for example, in the assessment of corrosion damage, the ultimate use of the material dictates the criterion used. In some applications the appearance is all-important, in others it is the time taken to perforate. For the structural engineer it is the load-carrying capacity that really matters. Unfortunately, some of these criteria are difficult to quantify. The effective loss in thickness by intercrystalline corrosion can only be judged by microscopic examination of sections cut from specimens, and the loss in mechanical properties is normally assessed by carrying out mechanical tests on specimens after exposure. Both these methods of assessment involve destruction of the specimens and a large number of replicate specimens are therefore required to obtain a corrosion damage time curve. A method commonly used by the laboratory worker to assess corrosion damage is measurement of change in weight. Whether this is positive or negative depends on whether or not the corrosion products adhere to the specimen. To interpret change in weight in terms of metal wastage usually entails the removal of corrosion products and this virtually destroys the corrosion test specimen, since the corroding kinetics can be changed completely by the removal of the corrosion products which can well be in the form of protective films.

A feature of the corrosion of aluminium and its alloys is that the normal corrosion time curve is not linear. In fact the corrosion rate tends to decrease with time. A method which was devised at the Fulmer Research Institute for the study of certain types of corrosion in aluminium alloys is capable of wider application. This is particularly true in cases where oxidation or corrosion is not linear. The corrosion specimens are in strip form and their deterioration with time is measured by the application of a comparatively light load in a four-point loading jig. The deflection under this loading is measured and the effective thickness of the specimen is calculated from the deflection, using the relationship $d=K^3\sqrt{\frac{W}{\delta}}$, where d is the specimen thickness, K is a constant determined in the uncorroded specimen, W is the total load and δ is the deflection. The load used is such that the maximum fibre stress in the specimen is in the elastic range, so that no permanent deformation occurs.

This principle can, of course, be applied to any shape of specimen, provided its moment of inertia of the section is calculable. The specimens used at Fulmer are in the form of rectangular section strips, so that the moment of inertia $I=1/12bd^3$ where b equals the width and d the thickness of the specimen. To obtain accurate measurements of the deflection it is preferable that the parts of the specimen which are in contact with the loading points of the jig on which the deflection is measured should be uncorroded, but the effect of corrosion at contact points on the accuracy of measurement, will, of course, become less the larger the specimens that are used and the wider the spacing of the loading points. Such a method of assessment is realistic from the point of view of the structural engineer and it is possible to obtain a corrosion damage time curve with a single specimen.

Enamel Finishes

Secondly, in controlled thermonuclear research a requirement arose for enamelled metals so protected that arc initiation was unlikely. A very high standard of finish was required to produce enamel coatings on aluminium with sufficient freedom from defects to give electrical insulation against 200,000 A.

The enamelling work was undertaken at Fulmer and the resulting work was tested in the following way. A wet brush connected to a 400 volt d.c. source was used initially as a test method to detect minute pinholes or other areas of inadequate electrical insulation. The brush was placed in contact with the enamel and the underlying metal was connected through a limiting resistance and a milliampere meter to the other end of the brush. When a pinhole came under the brush the circuit was completed and a deflection of the meter needle was observed. Although this technique revealed defects in some coatings which seemed satisfactory by visual inspection, it was nevertheless insufficiently stringent.

A more searching test is now carried out using a Ferranti high frequency Tesvac vacuum tester. This instrument has a probe which delivers an output of about 4 Mc/s at approximately 30 kV maximum. When the probe is brought near to a low-resistance area in an enamelled surface, the blue brush discharge changes in character and a bright point of light appears, accurately locating the defect. The test is non-destructive but, if the discharge is held on a particular spot for a long period, some enlargement of the defect might result due to the heating effect of the current.

The test is quick and might be useful in assessing the general quality of enamels apart from insulating properties, since areas of weakness in the enamel coating, revealed by this test, may form nucleation points for corrosion or spalling.

Plastic Replica Technique

Thirdly, a plastic replica technique has been developed, primarily for the inspection of components under fatigue stresses. The technique is simple and flexible and has been extended for use on various inaccessible components to inspect the surface for cracks and other defects. Inspection of the final replicas may be carried out with a simple optical microscope using reflected or transmitted light or with an electron microscope using secondary replicas.

Preparation of metal surfaces may be carried out by mechanical polishing, polishing in an electrolytic cell, or if carried out in situ, by the probe electropolishing technique. Polishing by this method is done with the aid of a metal pad, made the cathode, surrounded by a porous layer holding the electrolyte. The anodic dissolution of the sample is limited to the region of contact between sample and pad, which is of the order of 1 sq. cm. This area can be increased by moving the pad. After surface

Fig. 1.—Photomicrograph of weld.

Fig. 2.—Negative replica of area shown in Fig. 1.

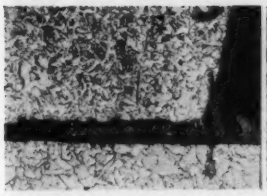


Fig. 3.—Replica of 70/30 brass fatigue test piece showing extensive cracking after 75% of life.

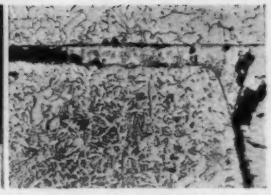


Fig. 4.—Replica showing large crack and Neumann bands in a ferritic steel.

preparation by one of the above methods, a solution of cellulose acetate is brushed on to the surface and cellulose acetate strip is pressed firmly over the solution. The solution requires a maximum of two minutes drying time and it is then readily removed.

The plastics replicas may be examined under reflected or transmitted light, and shadowing of the replicas improves contrast of fine detail such as slip lines. Secondary replicas can be taken from the original for more detailed examination by electron microscopy, for example, in the study of the early stages of crack formation.

This simple plastics replica technique gives faithful reproduction as shown in the photomicrograph of a weld (Fig. 1) and of a replica taken from the same area (Fig. 2), and would, for example, be useful for periodic inspection of welds in nuclear pressure vessels. It can be used to follow the fatigue life of part of a structure and gives a permanent record of change in surface topography, as illustrated in Fig. 3. The use of the technique in examining the surface of inaccessible components is illustrated by the crack shown in Fig. 4, which was revealed by local polishing of a large steel cylinder. A further advantage is that replicas can be taken of comparatively large areas available for only a limited time as a result, for example, of radiation hazard or the undesirability of taking the part out of service for any long time. The surface replica can then be examined at leisure in the laboratory and can be stored for record purposes.

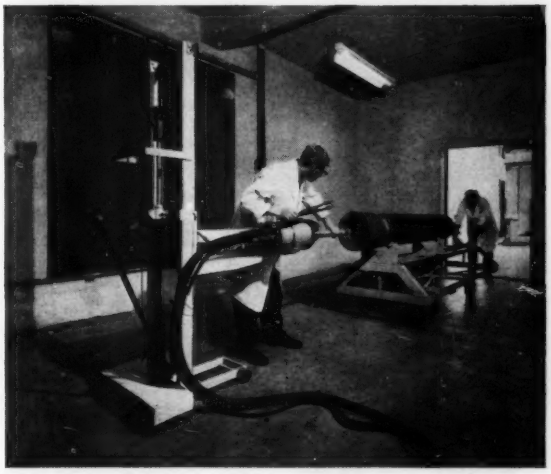
Radiography of Stand Pipes

AS sub-contractors to Whessoe, Unit Superheater and Pipe Co. produced stand pipes for Calder Hall and Chapelcross. Each required 112 stand pipes for charge/discharge and control rods; in addition, there were the burst slug detection tubes, irradiation and thermocouple tubes. All these components were stringently tested.

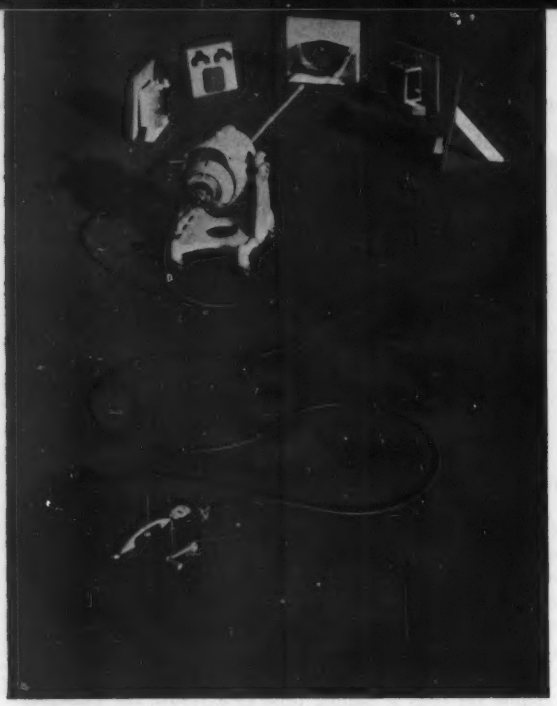
Jigs were made for each type of stand pipe or forging end so that the isotope could be accurately and quickly positioned in the bore of the tube. Welds within 18 in. to 24 in. of an open end were examined by simple ring fixtures which slipped easily over the ends of the tubes, with a crossbar and short tube extension welded into the centreline of the jig. The isotope was then slipped in through this hole on a handling rod previously marked for length. By such methods the radiographers were able to minimize the effects of radiation by having only one rapid movement to make with the isotope and no measuring or final adjustment to make with a live isotope. For the final welds on the stand pipes use was made of a self-centring spring-loaded isotope crawler.

For this first station Lloyd's Register of Shipping approved a technique using Iridium-192, 2×2 mm sources, and fine-grain film, which gave a penetrameter sensitivity of within 2%. With the prospect of the very much larger number of tubes required for the Bradwell reactors, again as sub-contractors to Whessoe, it was decided to examine the possibility of the Muller 150 kV rod anode and 300 kV conventional anode equipments for radiographing the stand pipe welds, and the welding on the thick section headers for the boilers. The installation can handle large numbers of welds; a 5-ton overhead travelling crane carries the work into a fully protected compound which is again further divided into a storage area where all the assemblies can be held until the weld radiographs are cleared by the inspectors. This is vitally important as one of the greatest problems on these contracts is the identification of specific sections on particular welds in any particular stand pipe. To ensure that no section escapes radiographic examination, one department of the works deals solely with charting the progress of individual welds and relating them to the radiographs, and checking that the radiographs have been inspected and released before the particular unit is cleared from the radiographic compound.

The 150 kV rod anode technique has given exceptionally good penetrameter sensitivity and Unit Superheater consider this to be one of the most important available.



Unit Superheater's 150 kV bay showing Muller extended anode X-ray tube head in position with section from control rod stand pipe being wheeled in.



Examination of several castings simultaneously using panoramic technique.

Projection of cobalt-60 source from container to centre of vessel for examination of complete circumferential weld.

Isotope Containers for Radiography

SEVERAL companies are now able to supply shielded isotope containers with remote control of source position. Typical of those now available is the range manufactured by Nuclear Engineering, Ltd., a subsidiary of G. A. Harvey, who have laid stress upon the need for easy transportation.

For this reason most of the smaller containers in Nuclear Engineering's range are trolley mounted. This feature is not possible, of course, with the larger containers of, say, 1,500 curie capacity upwards, where an overhead crane provides a more convenient form of transport.

Taking a gamma radiograph involves positioning the appropriate film behind the material or weld that requires examination and then moving the source container to a fairly close position.

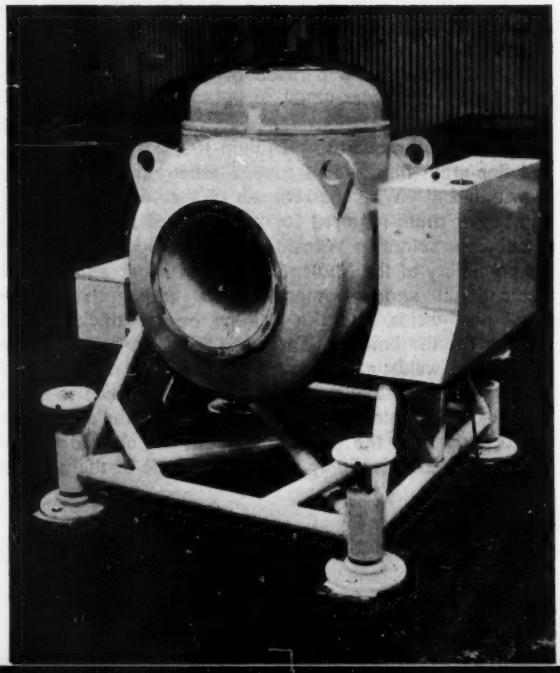
The source is moved out of its shielding container and along a rigid tubular guide connected to a port on the container face by means of a flexible cable remotely operated at a safe distance. The time of exposure depends upon the type of source and the nature and thickness of the material under examination.

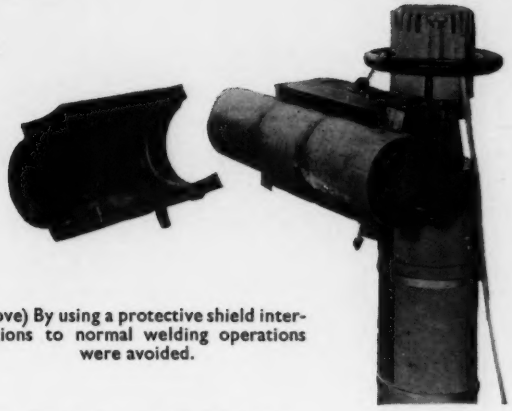
To avoid the difficulties associated with the radiography of large pressure vessels with only small access ports, Nuclear Engineering developed a special container in a tungsten copper alloy, the high density of which permitted a substantial reduction in size and weight. The container head—which weighs 50 lb—is also detachable from the supporting base and trunnions.

In addition to the rigid guide tubes flexible tubes can be supplied for occasions where the source cannot be moved in a straight line. The control box—which can be up to 20 ft away from the container—is manually operated; the latest model incorporates a counter which indicates the distance travelled by the source.

(Left) Model CR.10 for two gamma sources up to a maximum of 10 c cobalt-60 or equivalent.

(Right) Panatron 2,000 for a single gamma source of up to 2,000 c cobalt-60.





(Above) By using a protective shield interruptions to normal welding operations were avoided.

(Left) Rod-anode X-ray of 4-in. pipe prior to closure of 6-in. pipe joint.

Examining Welded Pipework

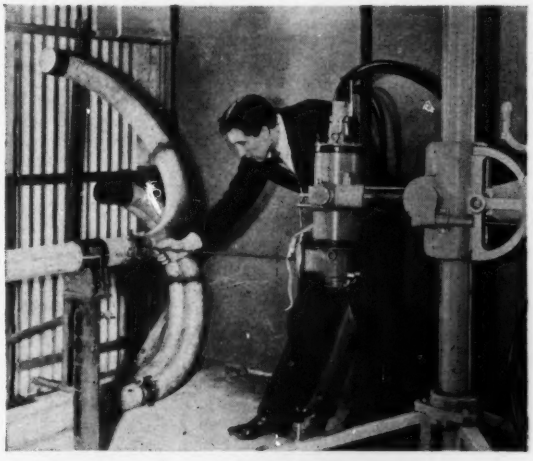
ONE of the most comprehensive non-destructive examinations in recent years concerned the heat exchanger circuits manufactured by John Thompson (Pipework) for the fast breeder reactor at Dounreay. The AEA not only required a 100% radiographic check, but insisted on a very thorough leak test.

Special procedures were necessary to carry out the radiographic examination. To provide the inner and outer circuits a 4-in. dia. pipe had to be inserted in a 6-in. dia. pipe. The joints in these pipes were slightly offset so that the inner weld could be radiographed (and repaired if necessary) prior to completion of the weld in the outer pipe. To provide for all contingencies when examining these welds, exposure techniques included single-wall single image, double-wall single image, double-wall double image, and four-wall single image procedure.

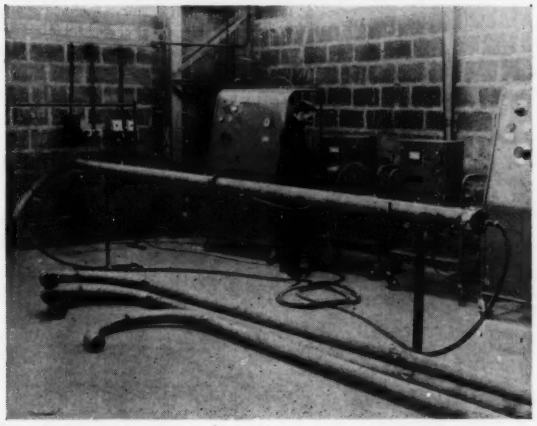
Radiography of the fast breeder circuits actually necessitated taking over 100,000 radiographs. John Thompson's made use of three types of X-ray equipment. (a) Constant-potential short anode tube of 150 kV, 20 mA and 3kW continuous output with a 4 mm focal spot. (b) Constant-potential rod anode tube, 150 kV, 15 mA with electrostatic focusing of the electron beam. Both these tubes were water-cooled. (c) Air-cooled short anode tank unit of 160 kV, 6 mA, 1.5 mm focal spot.

Because of the large number of welds and the possibility of interrupting work at frequent intervals John Thompson's developed a series of shielding units to fit pipes of from 1 to 6 in. dia.

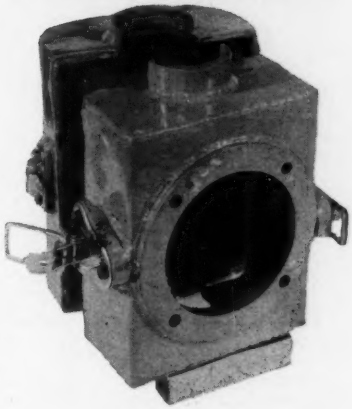
In addition to the 100% radiographic examination a gas test with nitrous oxide and an infra-red absorption gas analyser was made at the works. The piping was purged with nitrous oxide and then pressurized to 15 p.s.i. A further leak test was made at the site using portable halogen detectors. No leaks whatsoever were located.



(Above) Short anode X-ray tube taking conventional shot on pipe weld.



(Left) Gas test of tubular element at works.



(Right) Typical shielding unit developed by John Thompson (Pipework).

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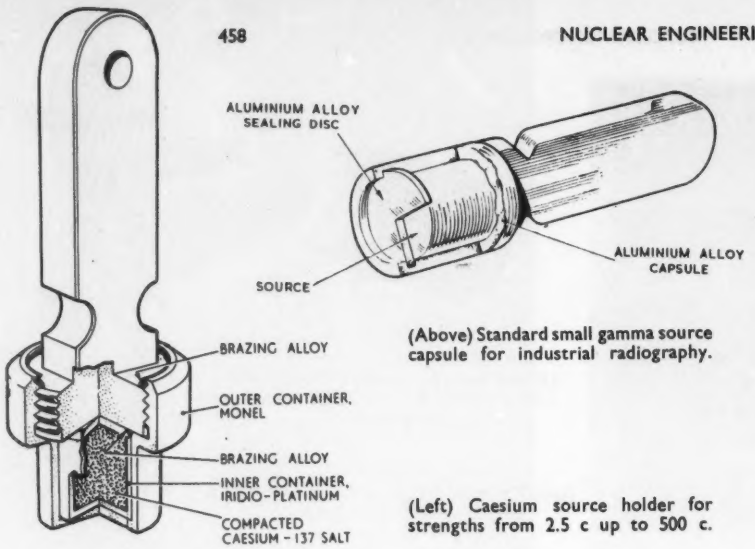


(Above) Standard small gamma source capsule for industrial radiography.

(Left) Caesium source holder for strengths from 2.5 c up to 500 c.

Radioactive Sources

THE main supplier for all radioactive sources in the United Kingdom is the Atomic Energy Authority, and although the bulk of prepared sources are marketed through the Radiochemical Centre at Amersham, for the present, cobalt, iridium and thulium can be ordered direct from the Isotope Production Unit at AERE, Harwell. For some years standard radiographic capsules have been available loaded with thulium-170, iridium-192, caesium-137 or cobalt-60. These are guaranteed sealed and safe, but the recommendation is made that an additional sheath be provided to guard against possible surface contamination.

Thulium-170

The γ-radiation from thulium-170 is of low energy and the tenth thickness is roughly $1\frac{1}{2}$ in. Al or $\frac{1}{4}$ in. steel. Its use is restricted to the investigation of relatively thin plate and light alloys, and it has found its main application in thickness gauges. Its half-life of 129 days is somewhat short for many industrial uses, but reactivation can be done. For radiography it is available in 2×2 mm and 3×3 mm capsules, the irradiation charge being £15 for the first 100 mc, plus £5 for each additional 100 mc.

Iridium-192

The γ-radiation from iridium-192, which has a half-life of 74.4 days, is a mixture dominated by the three energies 0.48, 0.60 and 0.61 MeV. The tenth value thickness is $1\frac{1}{4}$ in. steel or $3\frac{1}{4}$ in. aluminium. The short half-life is a disadvantage, particularly when compared with caesium, but there are certain advantages in a pile irradiated material, as against a fission product. High specific activities are available (several curies per gram) and for radiographic purposes cylinders 1×1 mm, 2×2 mm, 4×4 mm and 6×6 mm can be purchased. These cover the range of total activities of 250 mc up to 15 c. In addition to the initial charge for source material, which is a maximum of £12, the activation charge is £15 for the first 500 mc with £5 for each additional 500 mc.

Caesium-137

Being a separated fission product, caesium is a relatively recent introduction to the range of radioisotopes applicable to radiography. Supplies of this material are still limited, and very heavy demands will be made by the medical field, which will have an increasing demand for large therapy sources.

The tenth thickness for caesium-137 is something over $1\frac{1}{4}$ in. of steel and the isotope is of use, therefore, over the range $\frac{1}{4}$ in. to 4 in. The long half-life of 33 years makes it a particularly attractive proposition.

The caesium is prepared from fission products as caesium sulphate, with a specific activity in the region of 18 c/g, and a density of approximately 3 g/cc. Some contamination of caesium-134 is inevitable, but this is not expected to exceed 5%. Sources of to 1 curie have a pellet diameter of 3 mm and are encapsulated in a strong monel source-holder which is sealed with hard silver solder. Sources from 2.5 c to 500 c are prepared in eight standard sizes in which the active pellet diameter equals its length. Encapsulation is first in a 10% iridium-platinum liner, which is then sealed in a monel source-holder. Sealing of both containers is with a hard silver solder.

A new container has been designed for the 1,000 and 1,500 c sources, cylindrical in shape and without a handling tag, but with a recessed screw thread in the head for affixing a handling rod. Overall dimensions of the container are 2.75 in. long × 1.18 in. diameter, the diameter of the active material being 25 mm.

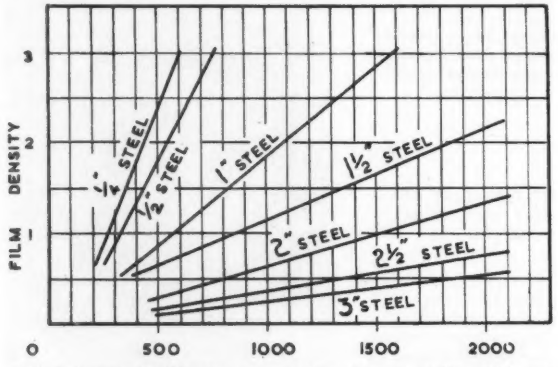
Minimum charge in the 2.5 to 500 c range is £100, while for 500 c the price is £725, the charge per curie flattening off considerably at the higher activities. Prices have now been established also for the 1,000 and 1,500 c sources, these being £1,225 and £1,500 respectively.

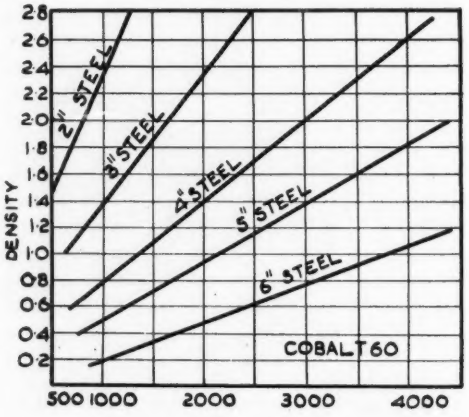
Cobalt-60

The most popular radiographic source is cobalt, which has been used since the introduction of radioisotopes for this purpose. With a half-life of 5.2-5.3 years, and emitting two gamma rays for every disintegration, of energies 1.17 and 1.33 MeV, sources are suitable for radiography in the range 2 to 6 in. of steel; if necessary, higher thicknesses can be accommodated if long irradiation times are acceptable.

Sources are available in a variety of forms. In addition to the 2 × 2 mm, 4×4 mm, 6×6 mm standard capsules, there is also the 12×12 mm capsule which is not provided with a handle, but comprises simply an aluminium capsule with overall dimensions 0.515 in. diameter × 0.56 in. long. The standard capsules will contain sources up to a few curies, and the 12-mm capsule up to about 45 c. For source strengths over and above this level an assembly of discs irradiated in the DIDO/PLUTO piles is recommended. These discs are 17 mm in diameter and they are enclosed in aluminium. The overall dimensions of the canned disc is 0.72 in. diameter by 0.162 in. thick. Specific activities will vary, but each disc will be roughly in the range 80-150 c, making the upper limit of activity around 750 c/in. length.

For low-activity sources a charge of £50/c is made, plus £2/c. For high-activity sources a sliding scale has been arranged, corresponding to £3/c for 500 c and £2/c for 1,500 c. A 1,000 c source will cost £2,250.





Typical exposure/density curves for (above) iridium-192 and (right) cobalt-60. Exposure is in millicurie-hours at 18-in. range.

Euratom and America

Statement by M. Etienne Hirsch

The U.S.-Euratom agreement was signed on November 8, 1958, by Mr. John McCone, chairman U.S. AEC and Dr. Heinz Krekeler for Euratom.

THE disappointing response of the European utilities to the invitation to submit concrete proposals for nuclear power station projects (the target being 1,000 MW by 1963) forms the background to the address given by M. Etienne Hirsch, President of the Commission, to the American Nuclear Society and the Atomic Industrial Forum in Washington on November 4.

The title of his address was "The State of the United States-Euratom Joint Programme," and after sketching the background to the U.S.-Euratom agreement, the President summarized the proposals that had been received, and went on to analyse the reasons for the poor response.

Basic Aims of Collaboration

The joint programme was conceived with two aims in mind; the first, of a political nature, concerned the strengthening of the unity of Europe and of the ties between Europe and America; the second had an economic background, and was based on the philosophy that power could be supplied to Europe while experience of full-scale construction was given to American manufacturers. To achieve these targets without drawing the U.S. Government or Euratom into the power-reactor business, the programme had to create incentives which would lead utilities to enter the field but leave them with a fair share of the responsibility. Because of changed circumstances, these incentives are now shown to be inadequate.

Tentative Proposals

An invitation for the proposals was issued on April 13, 1959, and by May 29 five utilities had expressed the intention of participating, further confirmed by letters over the next five months. Only the Senn proposal, however, has been finalized. A.K.S., of Germany, has expressed the intention of building a 150-MW organic-moderated reactor in collaboration with Interatom, the Atomics International affiliate, and Brown-Boveri, as architect engineers and prime contractors for the conventional portion. The Federal Government has expressed willingness to cover the difference in construction costs between the station and a conventionally fuelled station up to DM.100 million. A new company competent to proceed with this project has yet to be incorporated. Electricité de France, in collaboration with Centre Sud, of Belgium, have expressed interest in the construction of a 150-MW plant at Chooz, near the Franco-Belgian border, but the design has not yet been specified, although the site has been surveyed. Manufacturers' tenders are still being reviewed. The S.E.P. group of utility companies in the Netherlands is also nominally interested, but the final decision is not likely to be taken for some time. The West Berlin utility Bewag has also expressed interest in a 150-MW reactor, and the local authorities seem keen on the project and hope that it will be completed before the end of 1965, but safety problems are acute; no final decisions have been taken.

Reasons for Hesitancy

One of the reasons given for the absence of more concrete proposals was that the time-factor was too short, but the main reason is believed to be the short-term change in the energy situation in Europe. Although an average doubling time for the consumption of electricity of 10 years is still confidently predicted, the consumption of energy in Europe was 2% less in 1958 than in 1957, and the 1959 figures are likely to be less than the corresponding 1956 figures. Coal, in particular, has been strongly affected, the annual consumption of 415 million tons being 10% less in 1958 than in 1957. Imported coal is also cheaper than expected, the present price being around $14 per ton, as against $18, as was predicted. This alone implies that, to be competitive, the cost of power from nuclear stations must be 1.5 mill/kWh less. In addition, recent finds of oil throughout the world have lessened the dependence upon the Middle East resources, and correspondingly decreased the strategic value of nuclear sources. The reduced costs of fossil fuels, probably, result in part from the potential competition of nuclear fuels; also, the ultimate availability of nuclear-generated electricity has allowed the natural resources, such as the gas fields in France, to be consumed at a greater rate than would otherwise have been deemed advisable. Against this the capital cost of nuclear stations, predicted as around $350/kW, has been shown to be optimistic.

In spite of the short-term discouragements, the need for nuclear generation in years to come is unquestionable, and in view of this, large-scale experience on as many different reactor types as possible is required. Some of the economic assumptions on which the programme was based have changed for the immediate future, but the long-range perspective remains unaltered.

Euratom's Research

In contrast with the somewhat gloomy aspect of the constructional programme, the R. and D. programme has received enthusiastic support. Over 400 proposals have already been received, of which nearly 100 are joint U.S./European proposals. Over and above this, Euratom are preparing to expend a great deal on their own research programmes, $215 million having been allocated for the first five years. The Italian centre of Ispra is to be "Europeanized," and will house 1,500 scientists by the end of 1962. Negotiations are also in hand for the similar treatment of the Netherlands Petten centre, and the Karlsruhe centre in Germany. The possibility of a joint Euratom/Belgian reactor centre at Mol is also being investigated.

A number of contracts have been placed with individual concerns, as, for example, the fusion contract with the CEA and the contract for studies on a homogeneous reactor with the Dutch KEMA, and for further fusion studies with the Max Planck Institute.

Euratom regards it as its first and foremost duty to contribute with the Coal and Steel Community and the Economic Community to the creation of a united Europe, the measure of the success of this venture being the creation of European schools working with new European textbooks and the plans that are afoot for a European university. The ultimate goal is the creation of a prosperous United States of Europe.

TRANSLATIONS

Résumés of Principal Articles

La Condensation dans un Bac de Contention d'un Réacteur (page 431)

On s'efforce de déterminer la contribution que le transfert de chaleur par les murs d'un bac de contention peut apporter à la pression finale à la suite d'un accident grave subi par une conduite de vapeur dans un système réacteur. Des expériences ont été faites pour simuler les conditions. Au cours de ces expériences, de la vapeur à une pression variable fut injectée dans une chaudière Lancashire et on mesura la hausse de température et les changements de pression qui s'ensuivirent.

La chaudière Lancashire fut isolée en partie par un mur de briques, et elle fut aussi recouverte d'incrustations; on croit que les conditions créées dépassent celles que l'on rencontrerait effectivement dans la pratique. A la suite de ces expériences il a été déterminé deux formules qui ont permis une évaluation du transfert de chaleur lors de l'injection de vapeur et après pendant le rétablissement de l'équilibre. Une certaine prudence doit être observée à l'application de ces résultats, mais pour le moment il semblerait raisonnable de supposer que les résultats représentent une évaluation modeste et que la chute de pression impliquée par l'emploi de ces formules sera moindre que celle que l'on rencontrerait dans la pratique.

LE G 2 (page 435)

Le G 2 est le second des réacteurs de production de plutonium Marcoule. Sa puissance nominale est de 200 MW (t), et le rendement électrique net de l'installation est de 27 MW. Le noyau du réacteur est horizontal, sous forme d'un octogone reposant sur un piédestal de graphite; ce dernier est renfermé dans un bac sous pression en béton précontraint doublé d'acier. Les problèmes posés par le système de canalisations horizontales y sont examinés, en se référant particulièrement à la prévision d'une restriction de noyau adéquate.

Essais non Destructeurs (pages 438-459)

L'application rapide de l'énergie nucléaire a eu un effet remarquable sur la section de l'industrie qui s'occupe de l'inspection des produits de la construction mécanique. En fait, on pourrait même revendiquer en toute confiance que l'industrie nucléaire a transformé l'art des essais non destructeurs en une science.

L'énergie nucléaire éprouve un besoin spécial pour l'examen non destructeur par suite de l'adoption de normes de qualité matérielle plus strictes et de l'insistance sur une construction qui soit sans danger de nature.

Jusqu'à maintenant les méthodes d'essais non destructeurs en technique nucléaire présentant la plus grande valeur sont: la radiographie aux rayons X, aux rayons gamma et l'accélérateur linéaire; les ultra-sons; les détecteurs de fuites; les jauges d'épaisseur; les pénétrants; les particules magnétiques; la mesure des courants de Foucault et d'efforts.

Une vue d'ensemble de chacun de ces systèmes est donnée dans une série d'articles dûs à la plume de chercheurs spécialisés. Ces renseignements sont complémentées par d'autres articles décrivant des applications particulières d'essais non destructifs sur des projets de nature aussi diverse que le réacteur à "breeding" rapide de Dounreay et l'inspection d'éléments de graphite pour la centrale nucléaire de Berkeley.

Kondensation in dem den Reaktor umschliessenden Behälter (Seite 431)

Es wird versucht festzustellen, welchen Einfluss die Wärme-Uebertragung durch die Wandung des den Reaktor umschliessenden Behälters auf den endgültigen Druck haben kann. Den Anlass gab ein grösserer Schaden an einer Haupt-Dampfleitung in einer Reaktoren-Anlage. Es sind dazu Experimente durchgeführt worden, bei denen die wirklichen Verhältnisse nachgeahmt wurden. Dabei wurde Dampf mit variierendem Druck in einen Lancashire-Kessel eingeleitet und der Temperaturanstieg und Druckwechsel wurden gemessen.

Der Lancashire-Kessel war teilweise mit Ziegel-Mauerwerk isoliert und war ferner mit Rost bedeckt, und man glaubte, so schlechtere Bedingungen hervorgerufen zu haben, als sie in der Praxis vorkommen würden. Von diesen Experimenten sind zwei Formeln abgeleitet worden, die es ermöglichen, die Wärme-Uebertragung während der Dampf-Injektion und danach bis zum Beginn des Equilibriums zu schätzen. Eine gewisse Vorsicht wird bei der Anwendung dieser Resultate nötig sein, jedoch könnte man sich vorläufig dazu verstehen anzunehmen, dass die Resultate eine konservative Schätzung darstellen, und dass der Druckabfall, den man bei der Anwendung dieser Formeln voraussetzt, geringer sein wird, als der, den man in der Praxis antreffen wird.

G 2 (Seite 435)

G 2 ist der zweite Reaktor in Marcoule zur Herstellung von Plutonium. Er ist für eine Leistung von 200 MW (t) gebaut, die elektrische Netto-Leistung des Werks ist dabei 27 MW. Der Reaktorkern ist horizontal angeordnet in Gestalt eines Oktagons auf einem Graphit-Untergestell; das Ganze ist umschlossen von einem stahlgefütterten Hochdruck-Behälter aus vorgespanntem Beton. Die Probleme eines horizontalen Systems der Kanäle werden untersucht unter besonderer Berücksichtigung ausreichender Kern-Abschliessung.

Zerstörungsfreie Prüfungen (Seiten 438-459)

Die schnell steigende praktische Anwendung der Atomkraft hat einen ausserordentlichen Einfluss auf denjenigen Zweig der Industrie gehabt, der sich mit der Prüfung der technischen Erzeugnisse befasst. Man kann in der Tat behaupten, dass die Stromkraft-Industrie die Kunst der zerstörungsfreien Prüfung zu einer Wissenschaft erhoben hat.

Die Atomkraft bedarf ganz besonders der zerstörungsfreie Prüfung, weil viel schärfere Ansprüche an den Standard und die Qualität der Materialien gestellt werden und ferner auf unbedingt sichern Konstruktionen bestanden werden muss.

Soweit haben sich als die wertvollsten Methoden zur zerstörungsfreien Prüfung in der Atomkraft-Technik die folgenden erwiesen: Radiographie mit X-Strahlen, Gamma- und linearem Beschleuniger; Ultraschall; Leckage-Detektoren; Dickenmesser; Tränkungsmittel; magnetische Teilchen; Wirbelströme und Dehnungsmessungen.

Jedes der Systeme wird in einer Reihe von Aufsätzen behandelt. Die Mitteilungen werden durch weitere Artikel ergänzt, die besondere Anwendungen der zerstörungsfreien Prüfung beschreiben bei so verschiedenen Projekten wie dem schnellen Brut-Reaktor von Dounreay und der Untersuchung der Graphitkomponenten für das Kernkraftwerk Berkeley.

Condensación en un Recipiente de Contenimiento de Reactor (pág. 431)

Se hace la tentativa de establecer la contribución que la transferencia de calor a través de las paredes de un recipiente de contenimiento puede hacer a la presión final después de un accidente de mayor importancia en un conducto de vapor en un sistema de reactor. Se ha hecho un experimento para simular las condiciones. En el experimento, se inyectó vapor a una presión variable dentro de una caldera Lancashire y se midieron la temperatura y el cambio de presión subsecuentes.

La caldera Lancashire se hallaba en parte aislada por enladrillado y también estaba cubierta de escamas y se cree que representa condiciones peores que las que se encontrarían en la práctica. Después de hacerse los experimentos se han derivado dos fórmulas permitiendo que se calcule la transferencia de calor durante la inyección de vapor y después durante la aproximación a equilibrio. Puede que se necesite alguna cautela en la aplicación de estos resultados pero por el momento parece ser razonable suponer que la caída de presión implicada por el uso de estas fórmulas será menor que la que se enfrentaría en la práctica.

G 2 (pág. 435)

G 2 es el segundo de los reactores Marcoule de producción de plutonio. Clasificado a 200 MW (t), el rendimiento eléctrico de la planta es de 27 MW. El núcleo del reactor es horizontal, en la forma de un octágono descansando sobre un pedestal de grafito; éste va encerrado en un recipiente de presión de hormigón precomprimido revestido de acero. Se examinan los problemas del sistema de canal horizontal, con particular referencia a la provisión de restringimiento adecuado de núcleo.

Comprobacion no Destructiva (pág. 438-459)

La rápida aplicación de energía nuclear ha ejercido un efecto notable en aquella sección de la industria que se ocupa de la inspección de productos de ingeniería. En efecto, podría reivindicarse con toda confianza que la industria nuclear ha hecho que el arte de la comprobación no destructiva se vuelva una ciencia.

La energía nuclear tiene una necesidad especial para examen no destructivo debido a la adopción de normas más rígidas de calidad de materiales y la insistencia en una construcción inherentemente segura.

Hasta ahora los métodos más valiosos de comprobación no destructiva en la ingeniería nuclear son: la radiografía por Rayos-X, Rayos gamma y el acelerador linear; la ultrasónica; detectores de fugas; calibradores de grosor; penetrantes; partículas magnéticas; corrientes parásitas y calibración de tensiones.

Cada uno de estos sistemas va reseñado en una serie de artículos contribuídos por investigadores especialistas. Esta información es suplementada por artículos adicionales describiendo las aplicación específicas de comprobación no destructiva en proyectos tan variados como el reactor engendrador rápido en Dounreay y la inspección de componentes de grafito para la central de fuerza nuclear de Berkeley.

NEW BOOKS

Atomic Physics. (Vol. II of "Electricity, Magnetism and Atomic Physics.") By J. Yarwood. (644 pp., University Tutorial Press, Ltd., 1958.) 40s.

This book like so many of those issued by the University Tutorial Press is meant to be a comprehensive instructional textbook for the use of those students who have to gain their knowledge largely from textbooks, or have not got the ability or the time to read widely and selectively. It forms the second volume of the series of two—Volume I was devoted to "classical" Electricity and Magnetism—but the volumes are each self-contained and can be studied quite independently. The author is an experienced teacher and applied physicist, and both the experimental and theoretical aspects, including modern instrumental techniques and practice are clearly and adequately described. The standard is that required for a general physics degree or equivalent technical qualification in physics, and, although the book covers both atomic and nuclear physics, it does not cater for the theoretical nuclear physicist or the specialist nuclear engineer. The aim is to describe the fundamentals of electrons and ions in gases, the extra-nuclear structure of the atom, and the structure of the nucleus, and this it achieves most admirably. Starting from the conduction of electricity through gases and the discharge through gases at low pressures, positive-ray analysis, mass spectrometry and isotopes are then discussed, followed by atomic spectra and the periodic table. X-rays and X-ray spectra are the subject of the next chapter, and after dealing most elegantly with the principles of wave mechanics, the diffraction of neutral particles and the uncertainty principle, the first half of the volume concludes with a description of the various magnetic phenomena, the Zeemann effect, the Stern-Gerlach experiment and the gyromagnetic effects. The second half is devoted to discussions of natural and artificial radioactivity: the acceleration of particles and the disintegration of nuclei by such particles; the structure of the nucleus; the detection of nuclear radiations; nuclear energy; and finally cosmic rays. At all times the practical aspects are emphasized, both by quoting magnitudes and experimental details, and by describing the construction of suitable instruments and detectors. The text is surprisingly up-to-date, and the numerous references to the original scientific articles on which the text is based, together with the useful bibliographies at the end of each chapter not only provide adequate material for further reading but indicate the careful and extensive study the author has carried out. Finally, many worked examples are included, mainly from university degree examinations.

This textbook cannot be too highly commended. S.W.

Physics and Heat Technology of Reactors (Supplement No. 1 of the Soviet Journal of Atomic Energy. Translated and published by Consultants Bureau Inc., New York. Distributed in the British Commonwealth by Chapman and Hall, Ltd., London.) 174 p.p. (1958.) 168s.

This book is a collection of 18 separate papers covering a wide variety of topics in reactor physics (five papers), experimental nuclear and reactor physics (seven papers), and reactor heat engineering (six papers). These papers are only really suitable for the experts in the various fields dealt with so that the general technical reader will find only a small amount of interesting matter in them. Even the experts must have a considerable knowledge of mathematics. Most of the papers suffer from a lack of a nomenclature and a clear explanation of the terms used; for example, it is not clear what is meant by the term "porosity" used in M. A. Zimin's paper "Evaluation of Fuel Elements of Different Shapes."

However, for the experts, it is always useful to see other approaches to one's own problems. The common problem in engineering and science of assessing the accuracy required in a given result versus the amount of work needed to obtain that accuracy is illustrated in the first paper by G. I. Marchuk. The second paper, also by Marchuk, indicates that the Russians, like everyone else performing reactor physics calculations, are turning to electronic digital computers to perform the very large number of computations necessary to obtain a fairly complete picture of a proposed reactor. The next four papers on reactor physics indicate that the Russians have considered, if only theoretically, other moderators than light water. Mention is made of beryllium and deuterium (heavy water) as well as of graphite.

Two of the experimental physics papers are worthy of mention here. One by Antonov and his colleagues considers the slowing down of neutrons in graphite and heterogeneous uranium-graphite systems. The "pulse" method was used to obtain details of the slowing-down process. Departures from the simple carbon gas model, particularly in the final approach to thermal equilibrium, were obtained. The second, by Makarov and Samoilova, attempts to settle the old question of the effective destruction rate of Xenon-135 by radioactive capture in a power reactor by direct measurement in the reactor of the Demonstration Atomic Power Station (see Reports of the Geneva Conference 1955).

The only contribution which will be of some interest to the industrial nuclear engineer are the papers on engineering matters including three dealing with the thermodynamic cycles used in conjunction with power reactors. The paper by Gokhshtein indicates that working fluids other than water would give greater efficiencies. This paper ignores economics but the one by Kalafati shows that the cost of a cycle is one of the parameters to be included in an optimisation study. H.C.S.

Nuclear Reactor Physics. By R. L. Murray. (317 pp., Macmillan and Co., Ltd., London, 1959.) 30s.

It is not every professor that has a nuclear reactor to study at leisure and pass on its fundamentals to his students. The author is at present Professor of Physics at North Carolina State College of Agriculture and Engineering, and develops, in these pages, a branch of physics which was hardly suspected 20 years ago. The text is aimed at the graduate student in science and engineering, who apparently must have attained considerable mathematical talent, and takes the treatment of the practical reactors to a stage where one, with a flair for such things, could design the basic operations and give the engineers the magnitudes they require to make the expensive device a reality.

Like many U.S. textbooks, there is scant attribution to those who by original thought have made the object under discussion possible. There is no brief history, and one cannot find from the pages who invented and made the first reactor work according to plan. Or was there so much team work that no one has thought it worthwhile to sort out the original contributions? This would be unfortunate, because it is so helpful in teaching to bring a little drama into successes and failures in order to fix in the students' minds the realities of the situation, rather than a forced acceptance of a somewhat dry mathematical statement describing as near as convenient the mere facts. L.E.C.H.

Books Received

Directory of Nuclear Reactors. Vol I. (Power Reactors.) 214 pp. (At present available in English only.) The International Atomic Energy Agency, Kaerntner Ring, Vienna, 1. $3.50.

Introductory Nuclear Theory. By L. R. B. Elton. 286 pp. Sir Isaac Pitman and Sons, Ltd., Parker Street, Kingsway, London, W.C.2. (1959.) 40s.

Law and Administration. Vols. I and II. (Series X of "Progress in Nuclear Energy.") Editor: H. S. Marks. 994 pp. Pergamon Press, Ltd., 4-5 Fitzroy Square, London, W.1. (1959.) 189s.

Radio-Isotopes for Industry. By R. S. Rochlin and W. W. Schultz. 190 pp. Reinhold Publishing Corp., New York; Chapman and Hall, Ltd., 37 Essex Street, London, W.C.2. (1959.) 38s.

Uranium Production Technology. Editors: C. D. Harrington and A. E. Ruehle. 579 pp. D. Van Nostrand Co., Inc., Princeton, N.J, and 358 Kensington High Street, W.14. (1959.) 131s. 6d.

Technical Papers

Design and Testing of Large Gas Ducts

By A. T. BOWDEN and J. C. DRUMM

(*Presented at the Institution of Mechanical Engineers on Nov. 4, 1959*)

Duct work as required for the coolant circuit in the Calder Hall-type of power reactor presents special engineering problems because of the stringent demands regarding safety, flexibility, leak-tightness and low flow resistance. The last calls for small gas velocities, and this is usually achieved by using single lines of large-bore ducting. The diameter of the ducting at Bradwell power station—which forms the basis of this paper—is 60 in., the line by-passing the blower being of 35-in. bore. In normal operation, the temperature of the gas leaving the reactor is 390°C and that leaving the heat exchanger(s) 180°C. The maximum pressure in the circuit is 132 lb/in.² gauge and the pressure drop 7.6 lb/in.² Apart from other specifications covering special contingencies, the duct work must allow operation at 147 lb/in.² and gas temperatures of 420° and 200°C at the outlet of the reactor and heat exchanger respectively. The pressure drop contributed to the above-mentioned total by the duct system chosen, is 1.6 lb/in.²

The duct system finally adopted for the six heat-exchanger circuits at Bradwell (see Fig. 1) has rigid corners, a total of five in each circuit, incorporating a cascade of vanes to turn the gas round the corner with a minimum of pressure loss, and three tied bellows joints (indicated in Fig. 1) in each principal line of ducting.

Two major considerations govern the design of a large gas duct system: adequate flexibility and minimal thrusts exerted on the reactor and heat-exchanger shells. One can obtain flexibility by the provision of a number of bends in the system. This is based on the phenomenon that the cross-section of a bend, when subjected to a moment, becomes oval, relieving the longitudinal bending stresses in the outside fibres of the bend and shifting the point of maximum stress towards the neutral axis.

Compact systems with minimum thrusts are best obtained with bends of comparatively short radius of curvature, say, of the order of one pipe diameter. Right-angle bends in 60-in. ducts are normally fabricated from a number of short lengths of ducting with suitably mitred ends. Most of the work published on pipe-bend flexibility and stresses has been conducted on smooth bends, but it is generally accepted that mitred bends are rather less flexible and subject to higher stresses than smooth bends of the same leading dimensions. Also, there is evidence that the stiffness of bends with a small ratio of thickness to diameter increases as the internal pressure rises.

Table I

	Ducts		Condition
	Top	Bottom	
Thrust, ton ..	10.7	17.1	Hot with pressure
Moment at reactor, ton/ft	139	313	Hot with pressure
Maximum flexure stress in bends, ton/in²	7.8	3.75	Hot with pressure
Thrust, ton	11.6	22.3	Cold with pressure
Moment at reactor, ton/ft	118	400	Cold with pressure
Maximum flexure stress in bends, ton/in²	9.1	5.1	Cold with pressure

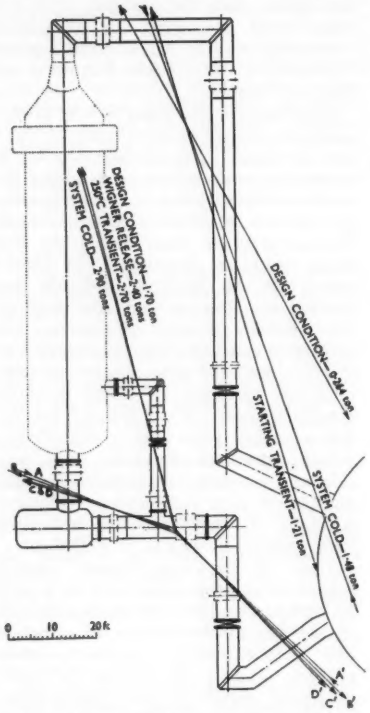


Fig. 1.—Duct thrusts due to thermal expansions. System cold. A=4.13 tons. A'=6.36 tons. 250°C transient temperature. B=3.28 tons. B'=5.35 tons. Wigner release. C=2.75 tons. C'=4.52 tons. Design condition. D=1.74 tons. D'=3.02 tons.

The order of magnitude of the forces and moments associated with the use of short-radius flexible bends in an arrangement similar to the Bradwell layout but without bellows joints and with mitred bends in place of stiff corners, are indicated by the figures shown in Table 1, reproduced on this page. The wall thickness is assumed to be $\frac{1}{4}$ in. and the flexibility and stress intensification factor the same as for smooth bends. Using the value given for the moment quoted in the table, a calculation by means of the Kellog expression yields the value of 3050 lb/in.² for the local bending stress in the wall of the reactor vessel for the case of the top duct in the hot condition. However, the maximum permissible local stress at the outlet nozzle of the hot reactor due to thrust is 900 lb/in.². In order to reduce the bending stress to the permissible value two extra bends would have to be incorporated in the system.

A duct design employing tied expansion bellows and large-bore ducts gives the most compact layout and the lowest flow resistance. Expansion bellows are employed in the ducting of all gas-cooled British reactors. Fig. 1 shows a thrust diagram for the Bradwell duct system. Calculations proved that the additional stresses in the reactor vessel wall due to the moment applied by the top ducts in the hot and cold conditions are only 185 and 72 lb/in.² respectively.

Lateral flexure of the bellows joints absorbs differential thermal expansion of the ductwork, the reactor vessel and the heat exchanger. A simple flexible tongue can be used in the particular conditions for transferring the axial pull exerted by the internal gas pressure across the bellows.

Meetings

December 1.—The Institute of Metals (Cadena Café, Cornmarket Street, Oxford, 7 p.m.). Meeting of Oxford Local Section. "Properties and Applications of Semi-conductor Devices," H. M. Ettinger.

December 3.—The Institute of Metals (Department of Chemistry, The University, Woodland Road, Bristol, 6 p.m.). Joint meeting with The Bristol Section of the Society of Chemical Industry. "Beryllium Metal: Production, Properties and Applications," Dr. G. A. Wolstenholme.

December 4.—The Institution of Electrical Engineers (Savoy Place, W.C.2, 5.30 p.m.). Medical Electronics Discussion, "Nuclear Magnetic Resonance," opened by N. Sheppard and R. E. Richards.

December 10.—The British Institution of Radio Engineers (London School of Hygiene and Tropical Medicine, Keppel Street, Gower Street, W.C.1 6.30 p.m.). "The Simulation of Nuclear Reactors and Power Plants," W. J. G. Cox and J. Dowsing.

December 11.—The Institute of Physics, South Wales Group (University College, Cardiff, 6.15 p.m.). "Nuclear Magnetic Resonance in Liquids," Dr. J. A. Pople.

December 15.—Joint Panel on Nuclear Marine Propulsion (The Institute of Marine Engineers, 76 Mark Lane, E.C.3. 5.30 p.m.). "Some Aspects of Marine Reactor Security," K. Maddocks.

December 15.—The Institution of Electrical Engineers (Savoy Place, W.C.2, 5.30 p.m.). Discussion, "Data Handling Problems in Atomic Installations," opened by D. Taylor.

December 16.—The Institute of Marine Engineers (Royal Station Hotel, Hull, 7.30 p.m.). Joint meeting of the Kingston-upon-Hull and East Midlands Section and the Hull Association of Engineers. "Steam and Steam Generation," J. Anderson.

December 30.—The Institute of Marine Engineers (Birmingham and Midland Institute, Paradise Street, Birmingham, 7 p.m.). "Energy from the Atom," Professor C. F. Powell.

Research Reports

AERE Report No: R-2983

The Release of Fission Product Gases from a Thin Film of U_3O_8 during Irradiation in the Dido Reactor - by F. J. Stubbs, P. J. Russell and G. N. Walton

THE work reported here is a sequence to experiments carried out previously by Stubbs and Walton and published at the First International Conference on the Peaceful Uses of Atomic Energy. As before, the present study aims at clarifying the mechanism of gaseous fission product release using a uranium oxide film as test object. In order to reduce the complexity of the conditions under which the measurements have to be taken, a thinner film is employed, 0.6μ in place of 3.0μ. Further, in order to simulate more closely operational conditions in present and future power reactors, a higher neutron flux is employed. The flux received by the sample in the BEPO experiment did not exceed 1.5 x 10^{12} n/cm^2,sec, whereas the flux received by the sample in the present experiments (in DIDO) was determined to be 2.7 x 10^{13} n/cm^2,sec.

The experimental arrangements were similar in both cases. The silica cell housing a platinum disc coated with the U_3O_8 (enriched uranium) film under test had a volume of 112 cm^3. It was surrounded by a heater winding and provided with carrier-gas inlet and outlet. The assembly was placed within, and near the blind end of, an experimental hole which projected into the heavy-water region of the DIDO core. A special air-cooling circuit was provided. It was found that, with the reactor working at 10 MW, the sample reached a temperature of 454°C largely as a result of nuclear heating. By operating the air cooling circuit this temperature could be reduced to 375°C and in the interest of safety it was considered essential to use the air cooling circuit continuously and to conduct all experiments with the reactor at full power at sample temperatures in the range 375-380°C. Consequently the heater winding could be disconnected.

Helium and nitrogen were used as carrier gases, conveying the fission product gases into the counting chamber where the gamma activity of the active gases was measured with a 3-in. sodium iodide crystal attached to a single channel pulse analyser. But gamma rays obtained from short-lived gases were found to be too numerous to resolve in a single crystal spectrometer. Therefore, a " pair production " spectrometer was set up as a tentative means of detecting high energy gamma radiation. In this arrangement, two sodium iodide crystals, each with its own photo-multiplier tube, are placed on either side of the main detector. The detector crystal and the two secondary crystals are connected to a coincidence unit. The interaction of a high energy gamma radiation with the main crystal gives rise to a positron/electron pair and a lower gamma energy radiation. The annihilation of the positron in the main detector crystal produces two gamma radiations of lower energy and the simultaneous detection of these by the two secondary crystals triggers the coincidence unit to accept the high energy gamma radiation. The efficiency of the " pair production " spectrometer was too low to permit quantitive measurements.

In the BEPO experiments the volumes of the silica cell and leads to the counting chamber were 300 cm in one case and 350 cm in another. The carrier gas moved at a rate of 1 cm^3/min. Samples trapped from the gas stream indicated Xe-135, Kr-85m and Xe-133 but not the presence of any rare gas of shorter half-life. In the DIDO experiments, samples trapped from a gas stream moving at about the same rate, showed a large amount of short-lived activity and only after this had decayed did the expected sharp peaks become evident decaying in the normal fashion. This discrepancy in the observations is attributed to the horizontal position of the experimental hole used in DIDO (as distinct from the vertical arrangement in BEPO), as a result of which the steeper temperature gradient from the inside to the outside of the reactor may have produced stirring along the tube faster than the gas flow. Quantitative measurement of Xe-135, Kr-85m and Xe-133 was made by trapping a sample of gas and following the decay. While this method facilitated precise estimation in the case of the two Xenon gases, Kr-85m could not be determined equally accurately, as not enough remained after the short-lived gases had decayed away. Details of the results are given in a table, partly reproduced below.

The measured rate of emission, expressed as a percentage of the calculated emission rate and called " measured percentage capture efficiency," is also given in that table and the " theoretical percentage capture efficiency " shown was calculated from the geometry of the irradiation vessel. The measured percentage capture efficiency of Xe-133 is greater than that of Xe-135. This appears to be due to differences in "hold-up time," i.e., the time between formation and measurement. The ratio of measured percentage capture efficiency to theoretical percentage capture efficiency should be unity and this is very nearly true for Xe-135 in the nitrogen experiments. Xe-133, on the other hand, has a comparatively long half-life and the experimental conditions favour occurrence of diffusion with respect to the Xe-133 atoms recoiling into the walls of the vessel and the backing of the uranium oxide film. Thus, the additional Xe-133 observed experimentally may have originated from these regions. Besides this diffusion phenomenon, certain adsorption phenomena may play a part but there is no direct indication of this in the results as listed in the table.

Results obtained using Nitrogen as carrier gas

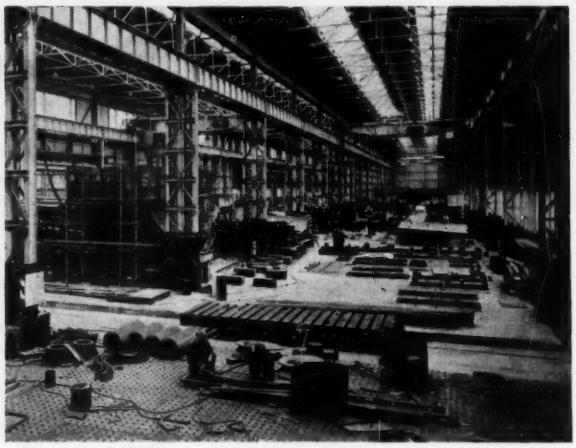
	Xe^{135}	Kr^{85m}	Xe^{133}
Calculated rate of emission by recoil (N_C) atoms/sec ..	243 × 10^6	59 × 10^6	255 × 10^6
Measured rate of emission (N_O) atoms/sec ..	27.0 × 10^6	7.7 × 10^6	90.0 × 10^6
Measured percentage capture efficiency (100N_O/N_C) ..	11.1	13.1	35
Theoretical percentage capture efficiency (100F_t) ..	12.5	7.3	12.5
Ratio of measured to theoretical percentage capture efficiencies	0.9	1.8	2.7

Results obtained using Helium as carrier gas

	Xe^{135}	Kr^{85m}	Xe^{133}
Calculated rate of emission by recoil (N_C) atoms/sec ..	243 × 10^6	59 × 10^6	255 × 10^6
Measured rate of emission (N_O) atoms/sec ..	3.8 × 10^6	2.3 × 10^6	13.4 × 10^6
Measured percentage capture efficiency (100 N_O/N_C) ..	1.6	3.8	5.3
Theoretical percentage capture efficiency (100F_t) ..	<2	<2	<2

Considerable attention has been paid in this work to ways of determining short-lived gases. For instance, it was found that, when equilibrium conditions had been attained in the counting chamber, the solid Cs-138 deposited on the walls of the chamber had reached a steady concentration, its rate of decay being equal to its formation rate, i.e., to the rate of decay of the Xe-138. The intensity of the Cs-138 was therefore a measure of the prevailing Xe-138 concentration.

Industrial Notes



A view of the rebuilt prefabrication and platers shops of Yarrow and Co. at Scotstoun, Glasgow.

A.E.I. have been awarded a £900,000 contract for the supply of switchgear to connect the Trawsfynydd power station to the national supergrid. The equipment will be made at Trafford Park, Manchester.

Humphreys and Glasgow, who recently terminated their agreement with **Alco Products** of New York in connection with marketing nuclear power plants, have signed an agreement with **Babcock and Wilcox** of London whereby they will be responsible for detail design and most of the conventional building of nuclear power plants incorporating pressurized water reactors designed and manufactured by Babcock and Wilcox.

Walter Somers have supplied **Richardsons Westgarth** with four rings weighing 2 tons each with an outside diameter of 80 in. and inside of 64 in. for installation at the Trawsfynydd power station. The rings were rolled in Somers' new high-speed ring mill and are part of a special cascade bend with a spherical body for use in the large CO_2 gas ducts between the reactor vessels and the heat exchangers.

Hobson of Wolverhampton have been awarded the contract for the active handling equipment for caves and cells to be installed at the CEGB's research laboratory at Berkeley. The contract calls for the design, manufacture and erection of three caves and 10 cells, and all additional remote handling and viewing apparatus.

Taylor-Hobson held an exhibition of precision measuring instruments at the Mayfaria Rooms during November. On display were the Micro alignment telescope used on nearly all nuclear power station construction, and a specially made periscope for viewing highly radioactive material.

The part played by lead in the nuclear industry was emphasized in a film, *Lead, the Enduring Metal*, shown recently by the **Lead Development Association.**

Isotope Developments have recently completed a tour of Belgium, Holland, West and East Germany, and Poland with their mobile demonstration unit. The unit, consisting of a working display of laboratory and industrial nucleonic equipment, visited universities, research laboratories, hospitals and manufacturing organizations.

Rio Tinto and **Dow Chemie,** the Swiss subsidiary of Dow Chemical, have jointly acquired the share capital of **Thorium Ltd.** from I.C.I. and Howards and Sons. Thorium Ltd. is the principal processor of crude thorium materials in the U.K.

Alco of New York have been awarded by Westinghouse a contract to build special heat exchangers and coolers for Dreadnought.

Three main gas duct circuits being built by **Yarrow and Co.** for Berkeley are nearing completion. Wall thickness of the ducts is $\frac{7}{16}$ in., increasing to 1 in. at the elbows. All plates are ultrasonically tested prior to rolling and welding, followed by a 100% X-ray of welds and magnetic crack detection around openings and weld preparations. The circuits have been fabricated under a sub-contract to John Thompson's. Recently shipped from the same works are 24 valve casings for the 60-in. transfer butterfly isolating valves which Hopkinson's are making for Bradwell.

Saunders-Roe and Nuclear Enterprises is the new name of Saro Nuclear Enterprises.

A two-day course on the problems of radioactivity in water and sewage works will be held at the **Manchester College of Science and Technology** on January 14-15. Details and application forms may be obtained from the Registrar of the College.

Rocol report that their Rocol Molytone 265 grease, used to lubricate the control rod bearings at Calder Hall, has withstood irradiations of 7×10^6 rad without deterioration. This lubricant is now being tested under extended periods of radiation in order to investigate the possibilities of using it in mechanisms closer to reactors.

Liquid Metal Applicators, 129 Mottingham Road, London, S.E.9, advise that their activities include the preparation and application of protective coatings for nuclear projects.

E.M.I. Electronics have received an order for a further 43 hand and clothing monitors from the AEA. Orders for the monitor, which is capable of monitoring both hands simultaneously for alpha and beta contamination, have also been received from Germany, Belgium, Israel and Australia.

Pye will supply two sets of reactor inspection television camera equipment for the Berkeley power station. This company are now supplying television equipment to three out of four nuclear power stations being built in the U.K. as well as for the Latina power station in Italy.

Collaboration agreements have been concluded between **General Dynamic's Electric Boat Division** and **Keith Blackman** to manufacture patented designs of axial fans with special slotted-blade formation, as installed in all nuclear submarines built in the U.S.A.

Mullard Equipment have introduced a comprehensive series of electronic subassemblies, named Norbits and Combi-Elements, for the construction of industrial control systems, digital computing elements, data processing equipment and measuring systems based on digital circuit techniques.

Research and Control Instruments are now marketing a new **Philips** scanning unit designed to sweep the energy spectrum at various speeds. The unit contains a helical potentiometer driven by a synchronous motor via a gear-change box with friction couplings. Four different scanning times, ranging from 3.5 to 100 minutes, are available.

Continental Distributors, 121 Earls Court Road, London, S.W.5, have been appointed the official agents for the **Nuclear Chicago Corporation** of the U.S.A.

We have now received from the AEA an additional list of contractors for Zenith.

John Laing and Son, Ltd., London. Portland cement, concrete and barytes aggregate blocks.

Ministry of Supply, R.O.F., Cardiff. Graphite reflector, graphic fuel rod assemblies.

H. M. Hobson, Ltd., Wolverhampton. Control gear, mechanisms and installation of control gear.

Vickers Armstrongs (Aircraft), Ltd., South Marston. Control rods, motorized source winding mechanism.

Sperry Gyroscope Co., Ltd., Brentford. Control rod position indicators.

Morgan Refractories, Ltd., Wirral, Cheshire. Fertile fuel pellets (thorium oxide).

Graviner Manufacturing Co., Ltd., Fareham. Graphite spacer pellets for fuel elements, storage cans (fuel).

Bell Precision Engineering Co., Crawley, Sussex. Fuel loading indicator board.

Electronics Division, A.E.R.E., Harwell. Control desk, health and nucleonic instruments.

Ashmore, Benson, Pease and Co., Stockton-on-Tees. Nitrogen gas holder.

Metropolitan Vickers Electrical Co., Ltd., Manchester. Vacuum pumps.

H. and E. Lintott, Ltd., Horsham, Sussex. Fuel storage safes.

Peter Spence, Widnes. Copper oxide pellets for nitrogen purification plant.

Personal

Mr. R. Wood.

Mr. D. B. Sole.

Mr. J. W. Meredith.

Mr. M. J. S. Clapham.

Appointments

Mr. R. Wood as the new Minister of Power.

Mr. M. J. S. Clapham as chairman of I.C.I. Metals.

Mr. B. D. Bains as technical sales manager of Hawker Siddeley Nuclear Power.

Mr. A. Neave to the board of John Thompson.

Mr. T. B. O. Kerr as director for finance and administration, **Mr. O. W. Humphreys** as director for research and technical development, and **Mr. W. J. Bird** as director for sales and marketing development of the General Electric Company.

Mr. J. Harrison as managing director of Atlas Copco (Great Britain).

Sir Gerald Templar as chairman of the British Metal Corporation.

Mr. M. Parkinson as vice-chairman and **Mr. J. B. Scott** to the board of Crompton Parkinson.

Mr. J. W. Meredith to the board of Simon-Carves.

Mr. C. W. V. Davis as head of the newly formed Industrial Products Division of Research and Control Instruments.

Mr. H. Slack to the board of Kelvin Hughes as sales director.

Mr. F. Burgess as chairman and **Mr. J. W. Plowman** as vice-chairman of the British Valve Manufacturers' Association.

Mr. W. M. Grainger and **Mr. D. D. Carrington** to the board of Walter Somers.

Mr. G. C. Panes as London manager of Hopkinsons.

Mr. R. A. Gilbey as general manager, Amersham Works, and **Mr. E. Ford** as northern regional manager of Dewhurst and Partners.

Mr. D. K. Fraser to the board of G. A. Harvey.

Prof. C. F. Carter as a member of the council for Scientific and Industrial Research.

Mr. D. G. Hill as manager, air filter department of Air Control Installations.

Mr. F. C. Braby as chairman of the Council of the British Non-Ferrous Association.

Dr. R. Hunter as chairman of the British Steel Castings Research Association.

Overseas:

IAEA third board of Governors are: **Mr. D. B. Sole** (South Africa) chairman; **Dr. K. Petrzelka** (Czechoslovakia) vice-chairman; **Mr. I. Fahmy** (United Arab Rebublic) vice-chairman.

Mr. G. J. Fergusson, chief physicist, New Zealand Institute of Nuclear Sciences, to the staff of the U.N. Scientific Committee on the Effects of Atomic Radiation.

Dr. E. Pohland (Germany) as general manager and **Dr. R. Rometsch** (Switzerland) as research director of Eurochemic.

Mr. D. G. de Graeff to the board of Tracerlab (Holland).

Mr. J. C. Clarke as manager of New York operations office of the AEC.

Mr. S. W. Nitzman as manager of the U.S. AEC's Schenectady Naval Reactors Operations office.

Mr. L. E. Whitmore as director and general manager, polyethylene div., **Mr. J. F. Widman** as director and general manager, chemicals div., and **Mr. R. Wilson** as a director and general manager, alloys div., of Union Carbide.

Dr. H. R. Ambler as the scientific adviser to the U.K. High Commissioner in New Delhi.

Mr. N. H. Woodruff as director of the U.S. AEC's office of health and safety.

Dr. H. Rudolph, formerly of EURATOM, as head of business management of the European Productivity Agency.

Mr. N. R. Crump to the board of International Nickel of Canada.

Dr. G. K. Teal as head of the newly formed Central Research Laboratory of Texas Instruments.

Mr. R. W. Dickinson as director of the Sodium Reactor Department of Atomics International.

Resignations:

Mr. A. S. D. Barrett from the board of Edwards High Vacuum, to become an independent consultant.

Mr. L. Clarke as chairman of Crompton Parkinson.

Retirements:

Mr. T. W. Heather, assistant managing director of G.E.C., after being a member of the board for 21 years.

Tours:

Sir Friston How, secretary of the U.K. Atomic Energy Board, of South Africa where he visited uranium mines.

Mr. F. Hamill, Mr. H. D. Binyon and **Mr. K. A. Macdonald** of the Scientific Instrument Manufacturers' Association, of the U.S.S.R. to explore sales possibilities.

Mr. A. R. Newby-Frazer, senior chemist, South African Atomic Energy Board, of U.K. AEA establishments and major nuclear centres in Europe to study waste disposal methods.

Mr. J. A. McCone, chairman of the U.S. AEC, of Russian nuclear establishment during October. Mr. McCone also visited the U.K. and EURATOM headquarters.

Awards:

The Nobel Prize for physics has been awarded to two Americans, **Dr. E. Segre** and **Dr. O. Chamberlain,** for their discovery of the anti-proton.

Obituary:

Nuclear Engineering regrets to report the deaths of the following: **Mr. F. W. Leake,** sales manager (works administration) of British Insulated Callender's Cables, on October 14.

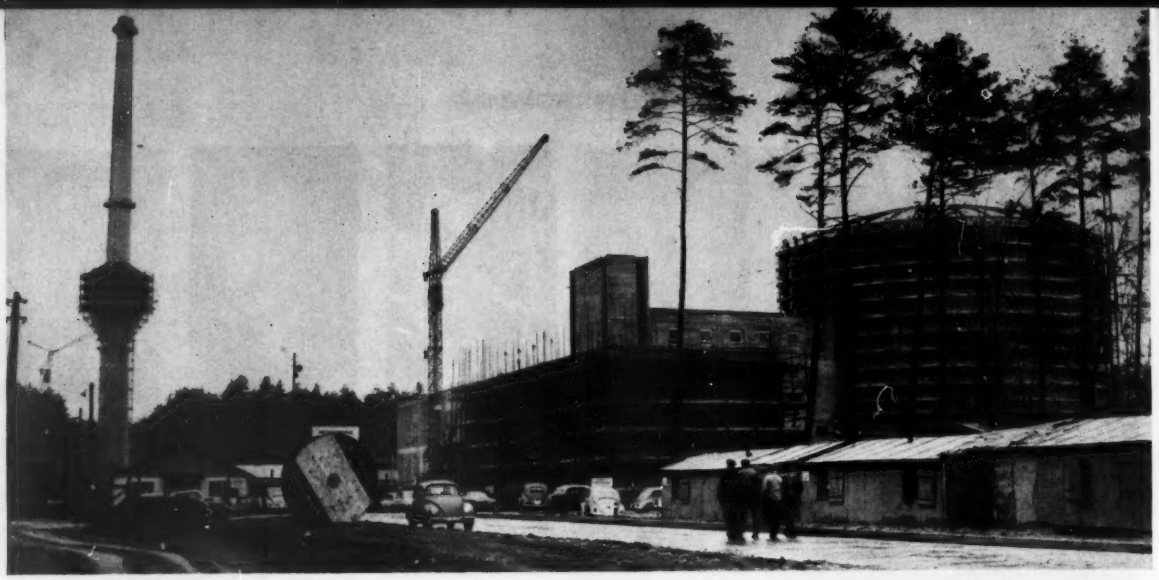
Mr. R. B. Dakin, deputy chairman and joint managing director of Walter Somers, at the age of 63.

Mr. W. J. Bird.

Mr. O. W. Humphreys.

Mr. T. B. O. Kerr.

Mr. J. Harrison.



The $50 million German research centre at Karlsruhe showing distinctive landmarks. On the left is the 340-ft-high exhaust chimney and on the right the 150-ft-high reactor building nearing completion. The centre—which is expected to be completed early next year—will house 1,500 research workers and scientists.

World News

International

OVER 200 SCIENTISTS, representing 29 different countries, attended the scientific conference on radioactive waste disposal held in Monaco, November 16-21, under the auspices of the IAEA with cosponsorship by UNESCO and FAO.

AN OFFICIAL COMMUNIQUE from Euratom headquarters states that the situation with proposals concerning power reactors to be built by 1963 under the U.S.-Euratom agreement is as follows: Italy, Elettronucleare-Senn have submitted detailed proposals for the construction of a boiling water reactor in conjunction with International General Electric; Germany, Interatom will build the AKS organic moderated reactor with Brown Boveri doing the industrial architecture, final details of which still have to be settled; France and Belgium, Electricité de France and Centre et Sud will build a station at Chooz near the Franco-Belgian border but definite proposals have not yet been fully worked out; Holland, SEP, an association of electricity producers, are undertaking a study; West Berlin, Bewag, have confirmed that they wish to take part in the programme as soon as possible.

A NEW COMMITTEE, the European-American Nuclear Data Committee, has been established by the European Nuclear Energy Agency, in agreement with Euratom, the U.S.A. and Canada, to assure collaboration in the measurement of nuclear properties.

GAS-COOLING AGREEMENT for exchange of information has been signed with the U.S. This covers design construction and operation of AGR types over a period of five years.

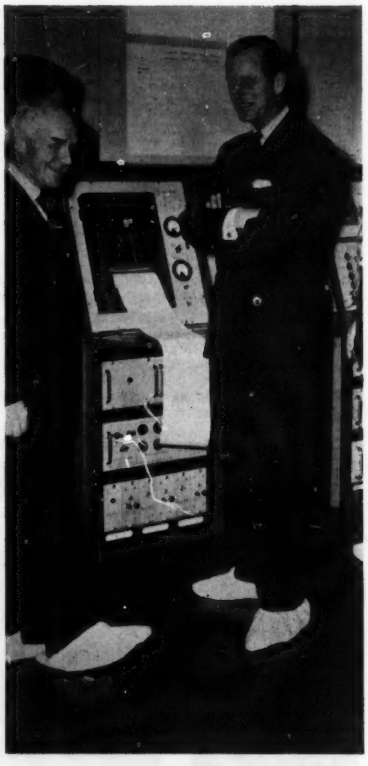
FIRST ANNUAL REPORT of the IAEA to cover a full operational year (July 1, 1958-June 30, 1959) has been submitted to the General Assembly by the Director General of the Agency, Mr. Sterling Cole (U.S.). The report was approved by the General Conference of the Agency at its third regular session in Vienna recently.

United Kingdom

DFR CRITICAL. Arriving too late for our reactor briefs is the news that the fast breeder at Dounreay achieved criticality on November 14. It will be run at low power for a period of some months.

NUCLEAR DATA, for design of reactors, will be the responsibility of a new laboratory which recently came into operation at Harwell. Under the Nuclear Physics Division of AERE, the laboratory which extends over 20 acres, houses an extensive range of neutron time-of-flight spectrometers. Main neutron generator in the laboratory comprises an electron linear accelerator used to generate an intense pulsed beam of electrons, which falls on a mercury target producing X-rays; these are then directed on to a uranium fast sub-critical assembly which in the pulse generates about 10 MW. Mean power rating is 2½ kW.

COLLABORATION AGREEMENTS for the development of nuclear power and techniques now exist between the U.K. and 15 individual countries as well as Euratom. A total of more than 1,300 overseas students have been trained at the three AEA schools, Reactor School Harwell, Calder Operations School and the Isotope School at Wantage.



The Duke of Edinburgh with Dr. T. E. Allibone, of A.E.I., at the opening ceremony of MERLIN on November 6. The research reactor is the first to be privately owned in the U.K.

THE ADMIRALTY submarine reactor programme at Dounreay is now under way according to a statement by Sir David Eccles, spokesman in the Commons for the new Minister for Science. Companies with the necessary scientific and technical experience in the north of Scotland are soon to be given the opportunity of tendering for development work.

NECESSARY APPROVALS for the acquisition and development of a site for thermonuclear research are being finally sought by the AEA. Proposed site is 175 acres within the boundaries of the Royal Naval Airfield at Culham in Oxfordshire. It is intended to move most of the thermonuclear research from Harwell and Aldermaston to the new establishment.

AN ADVANCED COURSE in radiation protection has begun at the Harwell Reactor School. The course, which is for both new entrants to nuclear health and safety work and those already working in these fields, will end on January 26, 1960.

THE GOVERNMENTAL Atomic Energy Office has been combined with the Lord President's office following the appointment of Lord Hailsham as Minister for Science. Mr. F. F. Turnbull will be in charge of the new office.

THREE AWARDS for films have been won by the AEA at an International Festival of Technical, Industrial and Agricultural Films, held in Rouen, France. The films are: "More Power from the Atom." "Radioisotopes in Industry" and "Metals of the Nuclear Age."

SCEPTRE IV, A.E.I.'s latest CTR torus machine at Aldermaston, began firing on October 27. The machine is a more refined version of Sceptre III in which great attention is being paid to maintaining conformity of the magnetic field to the physical geometry.

Belgium

DESIGN OF THE LABORATORIES for the Eurochemic centre at Mol, Belgium, is being undertaken by SDS, a group of architects and engineers from Denmark, Spain and Switzerland.

Canada

DELIVERIES OF URANIUM, under existing contracts to the U.S. and U.K., will be stretched out until 1966 under a plan recently announced by the Government. No change in price or quantity will occur. This follows the decision by the U.S. not to take up the options to buy Canadian uranium after the expiring of the present contracts in 1962-3. The U.S.AEC have announced that an advance payment of $2.50 would be made for each pound of uranium concentrate that was held for delivery in the stretch-out period.

Colombia

AN AUTONOMOUS PUBLIC ENTITY, to develop the study of nuclear energy and to ensure its use for peaceful purposes, the Instituto de Asuntos Nucleares, has been formed. The institute is to receive annual grants from the budget and will take over the assets of the Colombian Atomic Energy Committee.

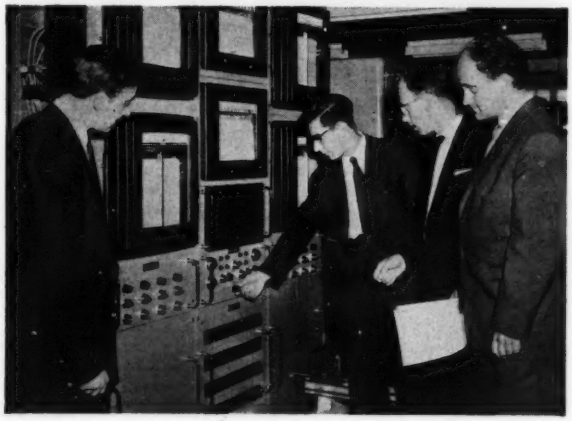
East Germany

MAYOR OF BERLIN, Herr W. Brandt, has had talks with Euratom with regard to the proposal to build a 150 MW power station under the U.S.-Euratom agreement in Berlin. The detailed technical planning for the project is under way but a decision has been deferred until after the Summit conference. It has been agreed, however, that Berlin could have the benefit of the Common Market's European Social Fund, should the need arise.

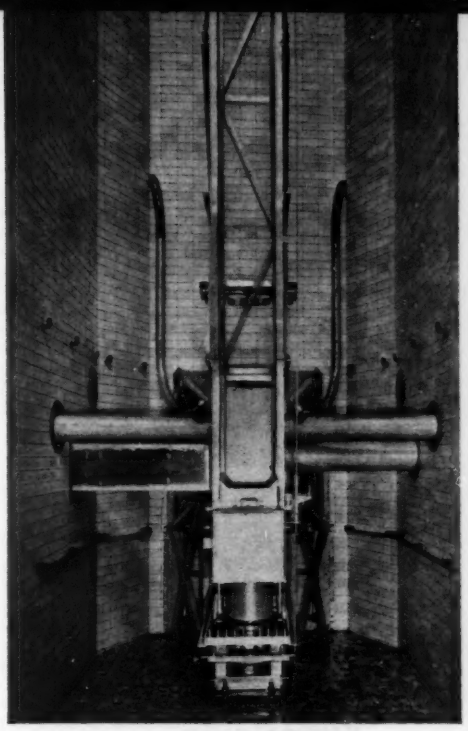
West Germany

AN INCREASE IN CAPITAL from DM 6 million to DM 9 million has been announced by Interatom. This is in order to finance the building of laboratories for research at the company's headquarters in Bensberg, Cologne.

MORE THAN £42½ MILLION has been spent by the Federal Republic on nuclear research according to a Government report. The report states that there are now 260 firms in West Germany engaged in nuclear work.



German nuclear scientists examining the burst slug detection equipment which is being supplied by Plessy Nucleonics for the 10MW NRX-type research reactor at Karlsruhe. On the left are Mr. M. Wilson and Mr. K. W. Cunningham of Plesseys.



A view of the beam tubes of the 5MW swimming pool reactor, Avogadro RS-1, at the Sorin nuclear research centre at Saluggia, near Milan in Italy. The reactor went critical on September 9.

Israel

IN A SPEECH outlining the tasks confronting the nation, Prime Minister Ben Gurion said that a nuclear power station will be erected in the Negev region.

Mexico

UNDER THE LAW, establishing the National Atomic Energy Commission, the uranium deposits recently discovered in the Chihuaha area have been included in the national mineral reserves. The deposits are on the northern side of the Mezquite mountains and in the northern part of the Gomez mountains.

Rhodesia

THE URANIUM PLANT at Rhokana, operated by Anglo-American of South Africa, has been closed down as most of the small quantity of uranium bearing ores has now been mined.

Rumania

CONSTRUCTION of a new laboratory for handling radioactive compounds will soon be completed at the Institute of Physics of the Rumanian Academy of Sciences.

South Africa

THIRD AMERICAN EXECUTIVE from nuclear engineering firms has paid a visit to the Union for talks with the Atomic Energy Board concerning the building of a £1 million research reactor. It is reported that six companies, American and British, are competing for the contract to supply the reactor which will be located in the Transvaal.

Sweden

A RECENT STATEMENT by the State Power Board indicates a further change in the Swedish nuclear energy programme. The Board have said that they plan to have a 50 MW foreign-designed boiling water reactor power station in operation by mid-1960. Negotiations with A.K.K. a nuclear power development consortium, formed by private and municipal producers, for co-operation will be pursued. Meanwhile plans for the R4/EVA, heavy water natural uranium power plant have been postponed.

Viet-Nam

A CHEQUE for $350,000 has been presented by the U.S.AEC to Ambassador Tran Van Chuong, towards the cost of a nuclear research reactor project. The reactor will be a 1-MW TRIGA, Mark II, using aluminium-clad, solid-fuel elements of enriched uranium in a homogeneous mixture with zirconium hydride which will act as a moderator. The core is surrounded by a canned graphite reflector and the entire assembly is immersed in a 21-ft pool.

Yugoslavia

DUMMIES WILL BE USED to re-enact the radiation accident in which eight people were involved and one lost his life in October, 1958, at the nuclear research centre in Belgrade. The IAEA will conduct the experiment with American and French technicians supervising. Dr. Jammet, director of the nuclear health service of the French AEC who treated the patients with bone marrow injections, will be in charge of the experiment.

UNIVERSITY OF BELGRADE has decided to establish an institute for the use of nuclear power in agriculture, veterinary science and forestry.

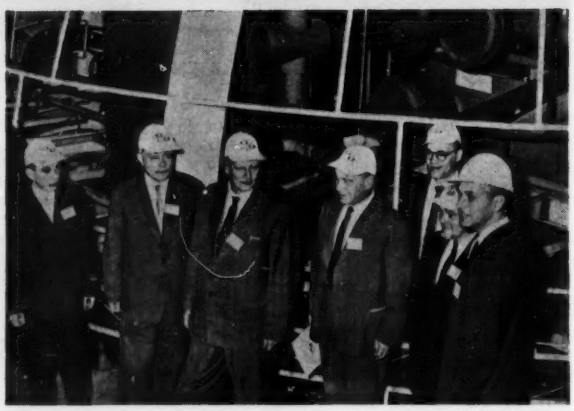
U.S.A.

A PILOT PLANT, costing $4,750,000, to reprocess reactor fuel elements, will be built at the Oak Ridge National Laboratory next year. The facility will be used for the reprocessing of fuel from a variety of reactors including fast-breeders and thorium types. The ceramic core fuel from the "Savannah" will also be reprocessed in the laboratory.

LIQUID FLUIDIZED BED REACTOR study is to be undertaken by the AEC. The Martin Company of Baltimore have been awarded the contract to build and operate the first critical experiment at a cost of more than $800,000. Fuel will be slightly enriched uranium pea-sized pellets, completely immersed in liquid in the cylinder-shaped core.

EXCAVATION WORK has started for an advanced-type cyclotron at the Oak Ridge National Laboratory. The facility, known as the Oak Ridge Relativistic Isochronous Cyclotron will cost approximately $3,725,000 and will be capable of accelerating protons up to 75 MeV and various ions up to about 100 MeV. A building 150 ft by 190 ft will be used to house the cyclotron.

FURTHER DOCUMENTS, totalling 39, concerning the production of heavy water by the dual-temperature hydrogen sulfide exchange process have been made available by the AEC. The information is for sale in either photostat or microfilm form.



Russian nuclear scientists being shown a mock-up of the reactor to power the ship *Savannah* at the New York Shipbuilding Yards. Prof. Emelyanov, head of the U.S.S.R. nuclear research, is second from the left.

NON-RADIOACTIVE TESTING has been undertaken by Atomic Power Development Corp. on the Enrico Fermi reactor. Major erection of the reactor components has been completed and dummy fuel elements are now being loaded to ascertain that the core will maintain a rigid shape.

ASSIGNED RESPONSIBILITY, to provide for the processing of spent nuclear fuel elements from privately and publicly owned reactors, has been made by the AEC to the Hanford, Oak Ridge, Savannah River and Idaho operations offices. This means that operations offices are now prepared to negotiate contracts with operators of reactors to provide for these processing services.

CONSTRUCTION PERMIT will be issued to the University of California for a 10 kW light-water moderated and cooled, enriched uranium fuelled reactor of the Argonaut type. The reactor is expected to be completed by the end of next year.

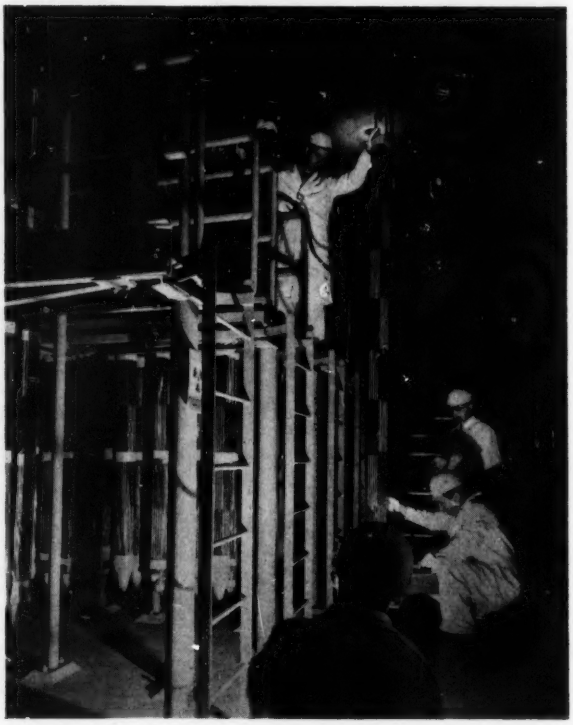
AN EXPANSION PROGRAMME, designed to double the capacity of the Westinghouse reactor evaluation centre at Waltz Mill in Pennsylvania, has been announced. New construction work on the facility is expected to be completed early next year.

FIVE URANIUM FIRMS have been accused by the AEC of violating safety regulations on the disposal of waste and have been ordered to take corrective action.

A SHIPMENT INCREASE of 42% has been reported by Radiation Counter Laboratories for the quarter ending September 30, as compared with the similar time last year. Orders during the 1959 period totalled $622,000.

WORK HAS BEEN STOPPED on equipment and plans for the Army's $7.5 million ionizing radiation centre at the Sharpe General Depot in Stockton, Cal. The authorities have stated that, as certain basic technical and economic questions about the process have not yet been determined, the construction of the centre at this stage would be premature.

KANSAS STATE UNIVERSITY are to install a General Dynamics TRIGA reactor of the Mark II type.



Fuel elements, four inches square and 11 ft 8 in. long for the Commonwealth Edison Dresden power station, being removed from storage at the plant. The 180 MW boiling water power station will hold 488 elements when fully loaded. The reactor diverged with a loading of 28 elements on Oct. 15

Processes and Equipment

For further information on any item please enter the relevant number on the Reader Service Card enclosed with this issue and forward the card to the address given.

Welding AGR Boilers

The manual welding of thick plate for boiler vessels is time-consuming and the quality of the weld is strictly dependent upon the skill of the operator. At International Combustion's Derby works recently it was decided to utilize automatic welding for part of the AGR boilers (E. F. P. Bennett, *Nuclear Engineering*, July-Sept., 1959, p.291).

The welding unit chosen for this purpose was a Lincolnweld universal tractor designed to weld in all the acknowledged downhand positions—butt, fillet and lap—with provision for horizontal/vertical welding in the 3-o'clock position. International Combustion successfully used this unit for welding the circumferential seams of the strakes carrying the support feet of the boilers.

The strakes—of 2¼-in.-thick plate—were formed into shells and automatically welded by an existing automatic unit. The dome was then attached while in the vertical position, and preparations made to weld this with the tractor unit in the 3-o'clock position. The section of the heat exchanger was mounted on the 18-ft diameter rotating table of a large Richards vertical borer. The tractor was mounted on a platform adjacent to the seam to be welded with a suitable staging, so that all welds could be viewed, checked or criticized during progress.

The general description of the section and procedure was as follows:

Outside diameter of section: Approx. 11 ft 4 in.

Material thickness: 2½ in.

Travel speed: Varying from 20-26 in./min.

Amperage: Approx. 350 to 375.

Voltage: 24 to 26.

Preheat temperature: Approx. 150°C.

After preheating, welding was commenced on the first section and a total of 144 runs of weld were required. This progressed very satisfactorily and very little trouble was encountered, although this was the first heavy structure to be welded with this unit and in this position. Upon completion the seam was X-rayed; and only one defect was detected, this being a ¼-in.-long fault which was cut out and repaired. Using the same procedure the second section was 100% successful. The same result was obtained on the third section, and the fourth section is now being completed.

The estimated time for hand welding these units was approximately 500 hours each section. The average time for welding with the Lincoln automatic unit was approximately 53 hours each section.

The average deposition rate was approximately 109 feet of welding per hour.

The Lincoln welding unit is simple in design, and very easy to operate in all positions. Although on this particular application the workpiece was rotated, the tractor is designed to travel with speeds varying from 6 in. per minute to 66 in. per minute, around vessels, or tubes, such as header pipes, with minimum diameters as low as 12 in. It requires no guiding, only setting.

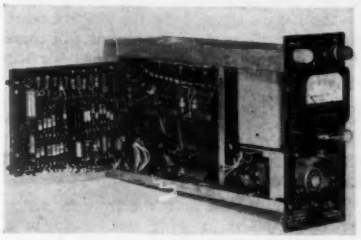
The unit can also be adapted for butt, fillet or lap welds, and it can be broken down for use as an internal welder in drums or vessels on longitudinal and circumferential seams. In the case of circumferential welds a pendulum arrangement ensures that the welding position is accurately maintained.

(International Combustion, Ltd., Derby.)
(Lincoln Electric Co., Ltd., Welwyn Garden City, Herts.)

1238

Monitoring Temperatures

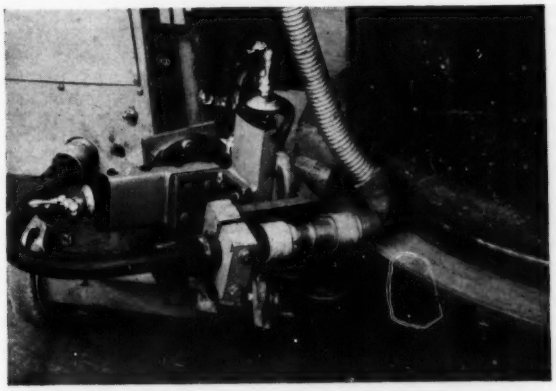
Primarily designed for monitoring the temperature at a given point in the fuel element channel of a reactor, the Ekco thermocouple trip amplifier utilizes the signal from a thermocouple to provide highly stable and accurate trips at two controllable levels. Meter indication is provided either for the temperature deviation below trip setting or the thermocouple temperature itself, depending on the position of a switch on the control panel. Lamp warning indications are provided on the front panel and the warning and trip relays each provide either two sets of change-over circuits and a short or open circuit pair or four sets of open circuit pairs which are connected to plugs at the rear of the instrument.



Ekco thermocouple trip amplifier.

Trip setting is by means of a 10 turn helical potentiometer on the front panel and the warning signal can be set, by means of a screwdriver adjustment at the rear of the instrument, to any temperature deviation below the trip setting. Full internal safety facilities are incorporated and the instrument will trip in the event of an open circuit thermocouple. Self-test circuitry can be operated by a switch on the front panel during routine maintenance checks.

The signal from the thermocouple is fed to the emitter of a transistor operating as an electronic "chopper" cutout. The base of this transistor is fed with a square wave signal at 700 c/s from a transistor multivibrator. Thus the voltage at the emitter of the "chopper" transistor alternates between zero and the signal voltage, and a square wave output, of an amplitude proportional to the input, is capacity-fed to a three-stage transistor a.c. amplifier. This is followed by an emitter-follower which is d.c. coupled to minimize phase shift in the amplifier feedback circuit. A transistor d.c. restorer is interposed between this emitter-follower and the output emitter-follower transistor to maintain the correct d.c. level with respect to the common line. The output transistor also feeds the independent warning and trip circuits which are identical in operation. The first stage of each trip



(Above) Welding AGR strakes with Lincolnweld tractor in 3 o'clock position. (Right) Complete set-up on Richards vertical borer.

circuit is a regenerative "flip-flop" formed by two transistors and triggered by the signal from the output emitter-follower when this exceeds about ±0.5V. The circuit will also trigger in the no signal condition. The relay transistor is controlled by the output of the "flip-flop" circuit so that when the signal output falls below the trigger voltage the relay is released. Two further transistors are employed in the safety circuits associated with each relay, these being biased by the 700 c/s signal from the multivibrator. Failure in any part of the circuit will cause the relay to be released, this being the trip condition.

(Ekco Electronics, Ltd., Southend-on-Sea, Essex.)

1239

Leak Detection

By employing the mass spectrometer tuned for a particular probing gas, leaks in a sealed system can be detected easily at comparatively high pressures with extremely high sensitivity. The technique is applicable to both vacuum and pressure vessels. The 20th Century mass spectrometer leak detector is a completely self-contained portable instrument which consists of a vacuum system of high pumping speed in which are incorporated the mass spectrometer system in addition to an ionization gauge and Pirani gauge. The system is so designed that components can be directly pumped and leak tested on the apparatus; the combination of Pirani gauge, ionization gauge and mass spectrometer covering the range of leaks from tens of lusecs to 10^{-7} lusecs.

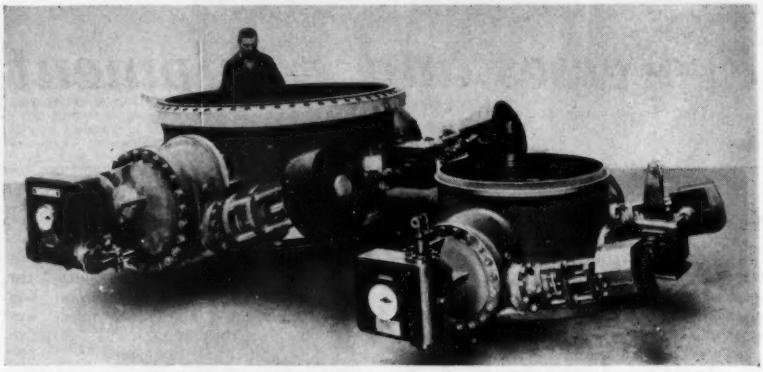
The mass spectrometer unit consists of a miniature 180° mass spectrometer which can be tuned to mass numbers up to 40. The sensitivity of this device is highest at the lowest mass numbers and the use of hydrogen and helium as the probe gases gives the highest sensitivity. Using hydrogen leaks of the order of 10^{-6} lusecs can be detected, whilst with helium 10^{-7} lusecs is the minimum detectable leak rate of the mass spectrometer ion current.

(20th Century Electronics Ltd., King Henry's Drive, New Addington, Croydon, Surrey.)

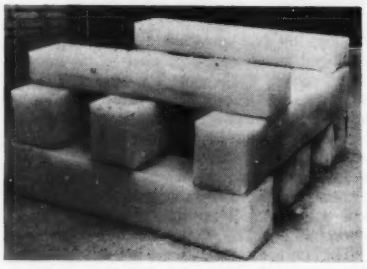
1240

Massive Polythene Mouldings

The availability of massive polythene blocks manufactured to high dimensional accuracy and free from shrinkage cavities will increase the interest of shielding specialists in polythene as a neutron moderator. Lead and polythene laminates were used in the "Nautilus" for primary shielding, the plastics being preferred to water for a number of reasons. The engineering problems associated with the provision of tanks to cover complex surfaces, guaranteed leak free in all circumstances, and able to withstand the accelerations encountered aboard ship are considerable. Radiolytic decomposition is an additional difficulty with liquid moderators whereas polythene can be moulded to almost any shape and stacked in places of difficult access and then secured, with comparative ease. Serious degradation occurs only after exposure to very high doses, the initial reaction being an improvement in the material as regards its structural characteristics.



(Above) Hopkinsons' Tansphere valves, 60-in bore and 36-in bore. (Below) Polythene blocks for shielding.

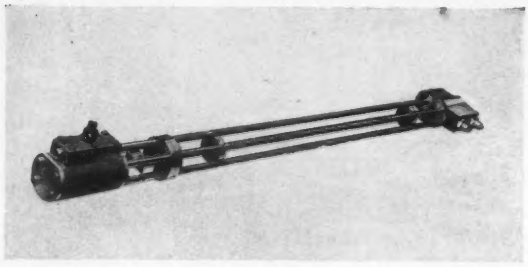


Goodburn Plastics have evolved new production techniques (patents applied for) based upon an extrusion moulding principle with strict temperature control at all stages but particularly during the cooling period. A wide range of sizes and shapes has been produced including slabs over 5 ft. x 4 ft. x 10 in. weighing more than 1,200 lb; this weight is furthermore not considered to represent an upper limit. Handling problems progressively increase, however, as the weight goes up. Boronated polythene blocks and slabs are also available.

Following moulding the forms are machined to size, an operation complicated by the high (2×10^{-4}/°C) coefficient of linear expansion. A final accuracy of 0.002-0.003 in./in. is achieved in normal production. Integrity is checked by X-rays and ultrasonics which would reveal and define the position of any flaws. Density of the finished product is 0.92 (the hydrogen concentration being some 16% higher than water by volume) and the maximum operational temperature for load bearing structures is in the region of 90°C.

(Goodburn Plastics, Ltd., Arundel Road, Trading Estate, Uxbridge, Middlesex,)

1241



Typical Neumo air-operated pump.

Tansphere Valves

Isolating valves in the large-bore ducting between the reactor and heat exchangers in gas-cooled, graphite moderated nuclear power stations have received the special attention of Hopkinsons, who have developed the Tansphere butterfly unit for these applications. Units have now been ordered for Bradwell, Hinkley Point, Trawsfynydd and Latina power stations. The bore of these valves ranges between 36 in. and 66 in. dia., depending on load.

As they are sited within the concrete biological shield, there is in their vicinity a probable level of radioactivity which precludes anything but a very short period of safe contact, and these valves are consequently required to have an exceptionally long working life without maintenance.

The butterfly disc is machined with a spherical face, and the seat against which it presses is machined at a tangent to this surface (hence the name Tansphere). The shafts supporting the butterfly disc pass through eccentrics which can be moved through a small angle to lift the disc on to its seat, or withdraw it. This feature allows the disc to be withdrawn and then turned through 90° without any scrubbing action between the valve disc face and its seat.

The electric control unit has two operating spindles; one performs the seating and unseating action just described, the other swings the butterfly through 90° in opening or closing. By this means, the butterfly, weighing up to 6 tons, can be closed in 10 seconds. The valve body is a steel fabrication and the disc of cast steel construction, and the whole valve, excluding the control units, weighs 9 tons for a 5-ft. bore valve.

(Hopkinsons, Ltd., P.O. Box B.27, Huddersfield.)

1242

Air-powered Pumps

Air-operated pumps which are said to be cheaper than flameproof electrically operated units are now being produced by Neumo of Peacehaven, Sussex. By regulation of the air supply to the motor these pumps can be arranged to stall at a certain delivery pressure and to start automatically when the pressure drops. The pump comprises either three or five main parts—a body with two valve chests on smaller models and four on the larger versions which deliver up to 1,500 gal/h.

A feature of the Neumo pump is that construction can be in stainless steel, cast iron, brass and either Fluon or H.D. polyethylene.

(Neumo, Ltd., South Coast Road, Peacehaven, Sussex.)

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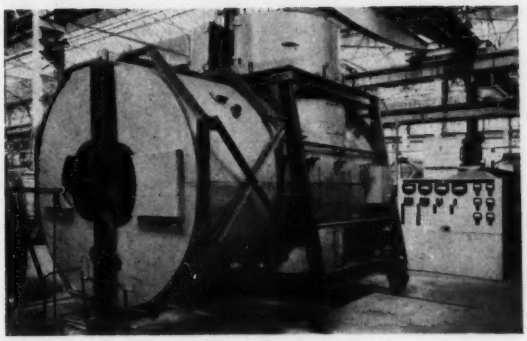

In order to test 60-in bore valves at the Kilmarnock works of Glenfield and Kennedy, Isopad Ltd. (Boreham Wood, Herts), made a large Isomantle so that the outlet valves could be heated to 800°F for a full pressure test.

1242

X-ray Inspection at Hinkley Point

Work is now well advanced at Hinkley Point on the site prefabrication of the 67-ft diameter, 3-in.-thick pressure vessel for No. 1 reactor and on the 90 ft high by 21 ft 6 in. diameter shells of the steam-raising units. The sub-assemblies for the shells of the steam raising units are fabricated by fusion-welding at the Dalmuir works of Babcock and Wilcox and shipped to site via Combwich. When welding on site is completed, the weld surface is prepared for examination and the joint X-rayed. A Marconi 250 kV mobile X-ray unit, TF 15553 is used for this purpose.

After stress-relieving, hydraulic testing and sealing, each completed shell weighing some 385 tons is ready for placing in position on its prepared foundations, there being six steam-raising units per reactor, placed three each side of the reactor building. The internals will be installed subsequently under the strictest clean-room conditions, the complete units having each a weight of some 1,250 tons.

The steel plates for the spherical pressure-vessel are formed at the Renfrew works of Babcock and Wilcox, each course of plates being pre-assembled on jigs to check shape and alignment. Groups of several plates are fully welded at the works, into assemblies suitable for transport to site. The plate assemblies as received from the works are built into complete circumferential courses in the site pre-fabrication shop. The joints between them are then manually welded, following which a thorough X-ray inspection is carried out.

The Marconi X-ray apparatus is of the constant potential type and the basic equipment comprises four main items—high tension transformer-rectifier unit, control unit, oil-cooled tubehead, and an oil circulator/cooler unit. A mobile trailer, which is towed into position on site, accommodates the complete apparatus, including the control unit. The equipment has an extended lift and a taller than normal tube column, providing a wide range of movements, essential for X-ray inspection of large units of this kind.

(Marconi Instruments, Ltd., St. Albans, Herts.)

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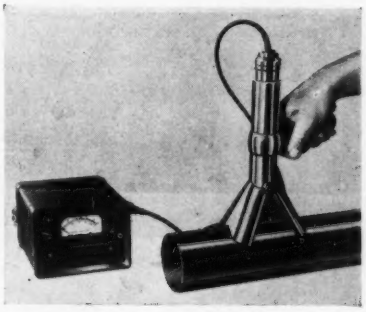
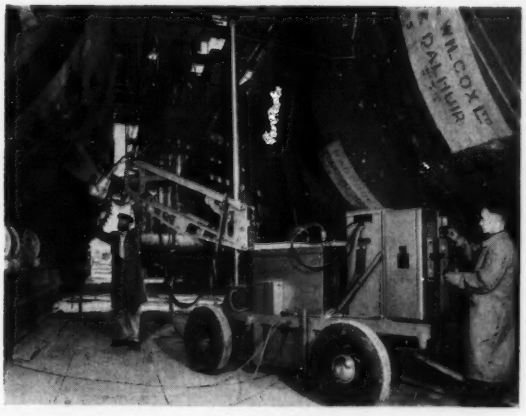


(Above) Ekco N 563 gamma backscatter gauge.

(Below) Marconi 250 kV mobile X-ray set in use at Hinkley Point.



Ultrasonic Examination

Ultrasonic methods of non-destructive testing are briefly mentioned on page 439; readers who require further information might care to know of companies specializing in the manufacture of this kind of test equipment.

Cawkell, for example, have developed ultrasonic sets for measuring the density of concrete and similar substances. The UCT equipment—which measures the time of propagation of a pulse of longitudinal vibrations through the specimen could be used for checking a suspect biological shield.

Kelvin Hughes, who have marketed ultrasonic sets for many years, recently introduced the Autosonic—a completely automatic inspection system whereby the probe is mechanically moved over the whole area to be examined. The Autosonic can thus be included in a production line; audible warning is given if a flaw is detected and the location of the flaw is marked not only on the specimen, but also on a separate record.

Curtiss-Wright ultrasonic test equipment makes use of both the immersion and contact techniques. The company's representatives, Scotts Engineering, have recently installed the largest Immerscope in the U.K.

(Cawkell Research and Electronics Ltd., Scotts Road, Southall.)

(Kelvin and Hughes Ltd., 2 Caxton Street, London, S.W.1.)

(Scotts Engineering (Newport) Ltd., Stafford Road, Newport, Mon.)

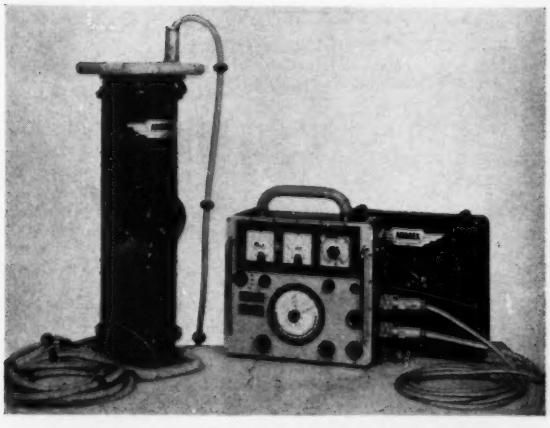
1244

Measuring Wall Thickness

One aspect of non-destructive testing that has not been discussed elsewhere in this issue of *Nuclear Engineering* is the application of a gamma backscatter gauge. This device can measure the thickness of pipe walls or sheet materials when only one side is accessible. With the Ekco N 563 gauge there are two ranges of measurement, 0 to 6.5 mm and 5 to 20 mm with an accuracy better than 5%. The N 563 is calibrated in terms of steel but calibrations for other materials can be supplied.

(Ekco Electronics, Ltd., Southend-on-Sea, Essex.)

1245



1246 A radiographic inspection service is now operated by B.I.X., Ltd., 73 High Holborn, London, W.C.1. The company, an associate of Holgar Andreassen, Copenhagen, uses Andrex X-ray sets. A 200kV unit is shown above. B.I.X. have recently opened an inspection department at London Airport.

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. 6d. each (including postage).

B.P. 809,671. Nuclear fuel elements. U.K. Atomic Energy Authority.

Basically, the element consists of the uranium charge, a protective envelope and a thin layer of a metal or alloy between the uranium and the envelope, bonded to the latter. The layer should diffuse readily into the uranium and the envelope at temperatures between 400 and 800°C. For an envelope of aluminium the layer may be nickel, cobalt, iron. The envelope may also be of beryllium, magnesium or an aluminium-magnesium alloy.

B.P. 809,693. Production of metals. P. Best and U.K. Atomic Energy Authority.

The invention concerns the production of cermets and metal-ceramic bonds. Uranium dioxide powder is compacted with a metal oxide powder (chromium, molybdenum, nickel, iron, niobium) and heated at low pressure or in an inert atmosphere in order to reduce the metal oxide to metal at the boundary with the uranium dioxide.

B.P. 809,833. Production of refractory vessels. P. Best, E. Proudfoot and U.K. Atomic Energy Authority.

A porous vessel is formed from a crude refractory compound which can be sintered. A coating of the purified refractory compound is then applied on the inside of the porous vessel and integrated with the body of the vessel by a sintering process. The coating may be applied initially by slip casting or by hydrostatic pressing. As a result, the body of the vessel consists of two integrated layers: crude sintered refractory compound externally and pure sintered refractory compound internally.

B.P. 809,892. Method of removing scale from zirconium. A.G. fuer Unternehmungen der Eisen und Stahlindustrie. (Germany.)

The only known chemical method for the removal of scale from zirconium consists of treatment with hydrofluoric acid. However, this is only effective with respect to scale formed at low temperatures. According to the invention, scale formed at high temperatures can be removed effectively by treatment with potassium hydrogen fluoride (KHF_2) which has a melting point of about 240°C. The treatment should be carried out in a nickel or copper vessel, should be short to prevent reaction with the zirconium (a matter of minutes) and the temperature should not exceed 300°C.

B.P. 810,090. Apparatus and process for continuous ion exchange. L. K. Cecil, A. A. Kalinske and Infilco Inc.

A comparatively small quantity of ion exchange material is needed if the liquid and the exchange material are thoroughly mixed, agitated and circulated for an extended period in the zone of treatment prior to separating the liquid from the exchange material. However, handling must be very gentle. Neither pumps nor impellers should be used. Air under pressure has been found to be the best means for mixing and circulation, as well as for conveying the ion exchange material from one zone to another. By way of example, the treatment of acid leach of a uranium sulphate complex with a highly basic anion exchange resin and an acidified ammonium nitrate solution is described, and an apparatus outlined fitted with the treatment chamber at a distance from the bottom of the tank.

B.P. 810,491. Oxidation resistant graphite articles. J. C. Fisger, Jr., and Union Carbide Corp.

The useful life of phosphoric acid as an oxidation retardant in a graphite article (block) can be extended by introducing phosphoric acid together with colloidal silica into the pores of the article.

B.P. 810,718. Nuclear reactor. Siemens-Schuckertwerke A.G. (Germany).

A novel design of power reactor, combining characteristic features of the boiling and pressurized water reactor, is described. It consists of one (vertical) pressure vessel and one steam circuit. The pressure vessel is divided into an upper and a lower chamber, only the walls of the latter being reinforced as in the case of the pressurized water reactor. Natural uranium is used as the fuel and the water (D_2O in a particular embodiment of the invention) circulates through the reactor serving as moderator, reflector and coolant as it passes through the respective regions of the plant. The upper chamber forms the evaporation zone and has a pressure of about 26 at; the lower chamber forms the reaction zone and is kept at a pressure of about 46 at. Communication between the two chambers is effected by nozzles fitted to the top of the fuel element channels and passing the coolant at an approximate temperature of 250°C into the evaporation zone. The coolant expands and forms steam at the aforementioned allocated vapour pressure. The steam leaves the pressure vessel, passes through the turbine and returns as condensate, cooled to 35°C, to the bottom of the evaporation chamber, where it starts on a fresh cycle. Transmission to the high-pressure reaction zone and thus to the fuel element channels, is effected by means of a pump.

B.P. 810,949. Titanium-base alloys. Metallges. A.G. (Germany).

The alloy contains 8.5 to 12% aluminium and 3.5 to 12.5% vanadium. It has a particularly high creep strength.

B.P. 811,042. Radioactive measuring device. Foxboro Co. (U.S.A.).

Reference is made to radioactive gauge systems of the type employing a strontium-90 source or the like, emitting beta-rays across an air gap to an ionization chamber, the specimen under test being placed in the air gap. In the absence of a specimen, ionization changes linearly with linear changes in the radiation reaching the chamber but with the specimen in position the degree of ionization depends on the radiation absorption characteristics of the material under test which may change with the changes in the variable to be measured. To counteract this and ensure linear measurement, an identical unit consisting of a strontium-90 source, air gap and ionization chamber is added, a rotatable disc being placed in the second air gap with a slot shaped in accordance with the predetermined variation in the absorption characteristics of the measured variable. The two units are electrically connected so that the outputs of the two ionization chambers are opposed to each other. Thus, when a change of the measured variable in the specimen produces a change in the output of the first unit unbalancing the indicator, balance is restored by rotating the aforementioned disc into the appropriate position. The amount of rotation required represents the "reading," i.e., the measured value of the change in the specimen under test.

B.P. 811,216. Welding apparatus. E. K. Richardson and U.K. Atomic Energy Authority.

A welding head with a bridge and clamps at the ends of the bridge to hold two pipes together endwise while a welding torch is rotated around the pipe ends to weld them together.

B.P. 811,217. Welding apparatus. E. K. Richardson and U.K. Atomic Energy Authority.

Refers to the automatic control of a welding head as described in the preceding specification, to adjust the rotation of the torch along the pre-set course and the variation of the current supplied to the torch as required by the different thicknesses of the material and by the nature of the weld.

B.P. 811,232. Device for monitoring the proton resonance in a liquid. Atomic Energy of Canada Ltd.

Details are given of the method employed, and the design of the instrument required, for monitoring isotopic purity of heavy water. The method employs the nuclear magnetic resonance technique, the sensitivity of which for detecting protons depends on the rate at which r.f. energy can be absorbed by the protons. The heavy water is placed in a (modulated) high magnetic field. As a result the protons present, having "spin ½," exist in one of two ways, spins parallel or antiparallel. The energy difference between the two levels leads to a Boltzmann distribution of population of the levels, with the lower state having a greater population. The heavy water is then passed to the detecting region where it is subjected to the r.f. field, under the action of which these populations are equalized. The amount of r.f. power absorbed in the process is directly proportional to the hydrogen content of the water. The arrangement described employs the conventional technique of sweeping the field back and forth through resonance, so that the absorption of power at resonance produces amplitude modulation of the r.f. voltage. A diode detector is used to give an audio frequency voltage, the wave shape of which is that of the r.f. modulation. It contains the sweep frequency and its harmonics. The second harmonic is an especially useful measure of the hydrogen content. The practical sensitivity of the instrument is 20 p.p.m., the response time about 30-60 seconds.

B.P. 811,528. Nuclear reactors and sub-assembly therefore. J. E. Draley and W. E. Ruther (U.S.A.).

It is proposed to make the coolant tubes in a graphite moderated water-cooled nuclear reactor from an alloy of aluminium containing 0.5 to 4% nickel. The same alloy is used for cladding the fuel elements. This material is resistant to high temperature water corrosion and has a low neutron capture cross section.